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RESEARCH CONCERNING FORECASTING ANOMALOUS PROPAGATION AT HIGH LATITUDES

Prepared by

S. C. Coroniti
J. R. Herman
G. E. Hill
R. B. Penndorf
G. F. Rourke

RESEARCH AND ADVANCED DEVELOPMENT DIVISION
AVCO CORPORATION
Wilmington, Massachusetts

Technical Report
RAD-TR-63-15
Contract AF19(604)-4092

Project 4603

Task 460304

FINAL REPORT (Item 1)

28 February 1963

Prepared for

ELECTRONICS RESEARCH DIRECTORATE
AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
Bedford, Massachusetts

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APPROVED

M. E. Malin

M. E. Malin
Director of Research

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ABSTRACT

Research concerning variations in the Arctic ionosphere and polar radio-propagation conditions has been carried out for the past several years. The objective has been to obtain information useful for forecasting anomalous propagation conditions and improving radio communications in the high-frequency band at high latitudes. Results of the research are given in the form of abstracts to all scientific reports and papers issued during the course of the work. Eighteen scientific reports and twenty-one related journal articles have been published; and in addition, seventeen symposium papers have been presented.

Appendix V-A contains an extensive bibliography concerning PCA, auroral zone absorption, and related geophysical phenomena. A brief discussion of the detection techniques, characteristics, and causes of anomalous high-latitude absorption is given.

A list of polar cap absorption (PCA) events occurring during the first six months of IGY is given along with the appropriate synoptic fmin charts in appendix V-B.

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Synoptic fmin charts for July to December 1957

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The authors wish to express their appreciation for the long-term cooperation, assistance, and many helpful suggestions given by Dr. P. Newman of the Electronics Research Directorate, AFCRL during the course of the work. The research benefited greatly from the interest and guidance of Messrs. H. S. Marsh and A. Sims, also of the Electronics Research Directorate. The studies and analyses reported in this document would not have been possible without the aid of a number of supporting personnel, including: Misses Doris Salmas, Estelle Guilbault, Susan Tyler; Mrs. Carol Kotce and Mrs. T. Scholler; and Mr. Gunther Vilbig; all of whom performed many hours of computation, tabulation, and data plotting.

I. INTRODUCTION

Radio communication in the high-frequency (HF) band (3 to 30 mc/s) is subject to frequent interruption in Arctic regions because of ionospheric and geomagnetic disturbances. Expanded civilian and military activity in these regions over the past several years, with a consequent increased demand for reliable communications, has necessitated a better understanding of the characteristics and causes of these interruptions to radio traffic (so-called radio "blackout"). Having such knowledge, it becomes possible to predict future behavior of radio-propagation conditions, so that optimum traffic control can be used to minimize the number of hours of outage.

The fundamental objective of the present investigation has been to obtain information useful for forecasting anomalous propagation conditions and improving radio communications at high latitudes. The research has covered several problem areas but has always been directed toward this objective. The problem areas studied can be categorized as follows:

1. Spatial, temporal, and stormtime variations of ionospheric parameters measured with vertical incidence ionosonde equipment, i.e.;

    a. Minimum frequency recorded -- fmin,

    b. F-layer critical frequency -- foF2,

    c. Highest frequency reflected from sporadic E layers -- foEs, and

    d. Spread F.

2. Solar-terrestrial relationships,

3. Relation between ionospheric and geomagnetic storms,

4. Relation between ionospheric and radio-propagation conditions,

5. Predicted performance of an HF radio network during ionospheric disturbances,

6. Atmospheric radio noise,

7. Special study of predicted performance of medium frequency (MF) groundwave during disturbances, and

8. Special study of experimental HF propagation across the auroral zone.

The study of items (1) through (4) is a natural forerunner for the predicted performance investigations in item (5). Atmospheric radio noise imposes a basic limitation on useful received signal strength, so the study of item (6) has been important to the predicted performance analyses of MF groundwaves and the HF network. Increased reliability of HF radio communications can only come from a detailed knowledge of the space and time variations of the ionosphere, thus a great deal of emphasis has been placed on a systematic study of the various ionospheric parameters (item 1). The results of this study indicate that anomalous changes in the ionosphere occur in a complex, but coherent, fashion. Further, under item (4), it has been found that anomalous changes in radio-propagation conditions at high latitudes can be explained in detail by the stormtime variations of the ionosphere. Investigations of solar-terrestrial relationships and the relation between ionospheric and geomagnetic storms (items 2 and 3) have been undertaken to find new precursors, or predictors, of impending radio-propagation disturbances.

Results and conclusions of the various investigations mentioned above have been presented in a series of technical reports issued at irregular intervals. The purpose herein is to make available in one volume the essential findings of the investigations. This has been done by compiling here the abstracts of all technical papers and reports issued during the course of the work. In essence then, this report is a highly selective bibliography on arctic radio propagation and the polar ionosphere.

Eighteen formal reports have been issued in the series mentioned above. Of these, eight have been printed by Avco RAD and are identified with an Avco RAD report number in the list of abstracts in section II. The other ten consist of reprints from journal articles, and in section II the appropriate journal is specified. The abstracts are arranged numerically according to report number, and following these, two final reports issued in connection with the special studies in items (7) and (8) are abstracted. The investigations discussed in Scientific Reports 1 and 2 have actually been carried out under an earlier program,* but they are included to make available abstracts for the complete series.

Several additional journal articles have been published during the course of the work which have not been submitted as formal reports. In a few cases, they cover related problem areas but do not significantly further the fundamental objective of the research. In the remainder, the subject material is derived from the Avco RAD reports. Nevertheless,they are included here because, in general, additional descriptive material has been added for clarity, and conclusions have been strengthened somewhat in the journal version. Abstracts of the journal articles are listed alphabetically according to author in section III, and where appropriate, the scientific report upon which the material is based is indicated. For completeness, titles of journal articles submitted as scientific reports are also included in section III, but without repeating the abstract.

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* Contract AF19(604)-2630.

Seventeen symposium papers have been presented during the course of the work. The essential contents of these subsequently have been published in journals or as scientific reports; accordingly, only their titles and place of presentation, arranged alphabetically according to author, are included in this report (section IV).

In appendix V-A, a rather extensive bibliography on polar cap and auroral zone absorption is presented.

A list of polar cap absorption events occurring in the first 6 months of the IGY (July to December 1957), reprinted from Scientific Report 18, is given in appendix V-B, along with the complete series of fmin maps used to define the events.

The following scientists and one engineer contributed to the research:

S. C. Coroniti,

J. R. Herman,

G. E. Hill,

N. J. Macdonald,

P. J. McKinnon (engineer),

R. B. Penndorf,

G. F. Rourke, and

D. W. Swift.

II. ABSTRACTS OF SCIENTIFIC REPORTS

Scientific Report 1, Polar ES, by R. Penndorf and S. C. Coroniti, reprinted from J. Geophys. Res. 63, 789-802 (1958).

"Data obtained by ionosondes and published by CRPL are used to investigate Es over the polar region. Three distinct types of polar Es exist, labeled Thule, Auroral Belt, and Mixed type. The Thule type, which is restricted to the area close to the geomagnetic pole (north of 73° geomag. lat.), shows a summer maximum occurring around geomagnetic noon. It follows Universal time. The Auroral Belt type occurs along the Auroral Belt and appears only at night. It follows local time. No appreciable change with season or sunspot activity is found. The mixed type is found along the demarcation line of these two types, for example, at Baker Lake; that is, during some months the Thule type prevails, whereas in other months the Auroral Belt type prevails. Another mixed type occurs at the southern limits of the Auroral Belt type, around 60° geomagnetic latitude. The geographic extent of each type is shown on a polar map. The strong correlation of Es and magnetic activity point to a direct or indirect influence of corpuscular radiation on the occurrence of Es in the polar region."

Scientific Report 2, The Diurnal and Annual Variations of foF2 over the Polar Regions, by S. C. Coroniti and R. Penndorf, reprinted from J. Geophys. Res. 64, 5-18 (1959).

"Critical frequency data, foF2, are analyzed in the polar regions for the period 1954 to summer 1957. The diurnal variation is largest in winter and smallest in summer. In winter little or no diurnal variation occurs north of 75°. The amplitude increases southward up to 11 Mc/s at 60°N with a minimum around 07h and a maximum between 12h to 14h. The daily variation is fairly symmetrical around the maximum. The pronounced daily variation lasts from fall through winter till spring. The annual variation shows a regular behavior, with steep gradients occurring around sunrise and sunset throughout the year. The latitudinal differences are small in summer, of the order of 1 Mc/s or less between 60° and 80°N, but large in winter. The lines of equal foF2 seem to fall between the geographic and geomagnetic latitude circles. The diurnal variation in the Antarctic is different from that in the Arctic during the southern summer (November to February) because a dip occurs around noon."

Scientific Report 3, Single Station and Synoptic Analyses of Ionospheric Data for the Arctic, by G. Hill and R. Penndorf, Avco RAD-TR-59-19, AFCRC-TN-59-365 (September 1959), 122p.

"Anomalous effects in the Arctic ionosphere were examined from two approaches. First, the time dependence of sporadic E, spread F, E, and F2 critical frequency data were studied for individual stations. The E layer, as expected, was found to be very regular. The F2 layer showed strong seasonal, diurnal, and geographical variations. Near the pole during the winter erratic variations in the F2 critical frequency were found. Sometimes the foF2 changed as much as 10 mc/s within a few hours. These changes are related to certain spread F forms. The occurrence of sporadic E was found to be more intense and more frequent at night in the auroral belt than further north. The statistics for Es $\geq$ 10 mc/s also followed this pattern. The number of Es occurrences was grouped into frequency bands 2 mc/s wide. It was found that they decrease from one band to the next higher one by a factor of about three.

"Second, synoptic charts of the F2 critical frequency data were prepared for the Northern Hemisphere (excluding equatorial latitudes). A polar stereographic projection of the Northern Hemisphere, which is especially suitable for Arctic work, was used in the analysis. Critical frequency data was first studied on a monthly basis. Monthly medians of the critical frequency of the E and F2 layers were arranged according to Greenwich Mean Time in three-hour intervals and plotted on the maps. Thus for each month there are eight maps, 00Z, 03Z, and so on. These maps were constructed for January, March, and June 1957, which roughly correspond to the seasons.

"Such maps can be used in determining the modes of propagation as well as the proper frequencies for communication links across the Arctic. In addition, a background for non-cyclic variations of a daily character is provided by this map series. Such non-cyclic variations have been analyzed during a five day period in July 1957. It is to be expected that besides diurnal, semidiurnal or tidal, and seasonal variations, smaller scaled variation in the layer structure may be examined. The average distance between ionospheric stations is on the order of 1000 km and about half or a third of that if only the continental areas are considered. Therefore the smallest layer variations which can be studied reliably are those with horizontal wave lengths of about 2000 km. Variations on a much smaller scale, or turbulence scale, were treated in a statistical way. The amplitude was considered, but not the phase or exact wave length. The amplitude of the electron density variations for this scale were then analyzed in the same manner as with the layer structure.

"Common to most of the monthly charts is a certain pattern in the large scale variations, which exhibit several outstanding features. In general there is a region of high critical frequency on the day side of the globe in low latitudes and a region of low critical frequency on the night side in high latitudes. The latter region is normally split up into three zones each having a separate minimum in foF2. This system rotates around the earth with the sun, and has a center of rotation between the Geographic, Magnetic, and Geomagnetic Poles.

"That is, the center of rotation is on the North American side of the North Pole rather than the Eurasian side. There is considerable distortion in the pattern as it moves around the globe at high latitudes, evidently due to the asymmetry of the geographic and geomagnetic latitudes. In addition, there is a marked seasonal influence on the size, intensity, and location of the basic pattern.

"The July series of synoptic charts have much the same pattern as the monthly maps for June 1957. In other words, the large scale (hemispheric) daily variations are roughly given by the variation of the monthly medians. There are however, significant departures in the foF2 global distribution from those indicated by the monthly charts even during this magnetically quiet period. These departures are systematic and form patterns or "disturbances". The average velocity of these disturbances during the five day period was roughly toward the west-southwest at 160 km/h. The average size of the measured lows during the five day period was about 2600 km and the highs 1500 km."

Scientific Report 4, Propagation of HF and VHF in the Arctic Region, by R. Penndorf and S. C. Coroniti, reprinted from IRE Trans. Comm. Sys. CS-7, 121-125 (June 1959).

"All the available ionospheric records for stations located north of 60° geographic latitude and for the period 1954 to 1957 were critically analyzed. The F2 region shows two distinct types: one, north of 75° with very little or no diurnal and seasonal variation in the critical frequency; the second, south of 70°N, exhibits diurnal and seasonal variations as well as those correlated with sunspot activity. Communication by means of abnormal ionization, such as Es, is known. We found three types of sporadic E abnormalities; namely, the Thule type, the Auroral-Belt type, and the Mixed type. These types show a distinct geographic distribution which is of utmost importance for planning communication links within the Arctic as well as between continental U.S. and the Arctic. Auroras can be used as reflectors or scatterers."

Scientific Report 5, Anomalous foF2 Variations in the Antarctic, by G.E. Hill, Avco RAD-TR-60-13, AFCRC-TN-60-362 (April 1960), 47 p.

"The daytime minimum in the F2-layer critical frequency, which is often observed in the Antarctic, is explained on the basis of a vertical shear in the horizontal wind (neutral air) and the resulting movement of charged particles in the presence of the earth's magnetic field.

"The diurnal variation of the F2-layer critical frequency, as expressed by the noon minus the midnight value, D, is normally positive, but in the case of the daytime minimum, is negative. For a given month, the value of D has been found to depend upon both the geographic latitude and the geomagnetic dip. The D values from the Northern Hemisphere have been compared with the D values of the Southern Hemisphere for a time separation of six months. The comparison gives good agreement in the region of the graphs where there are stations for both hemispheres. (Due to the asymmetry of the geomagnetic field, several stations in the Southern Hemisphere are found to have no corresponding stations in the Northern Hemisphere on the basis of geographic latitude and geomagnetic dip.) It is also noted that the negative D values occurred almost entirely in the Southern Hemisphere, and in that region where there are no corresponding Northern Hemisphere stations.

"A three-level model of the F region has been developed for the purpose of demonstrating the effect of a vertical wind shear on the electron concentration. The results of electron-density computations for several cases have shown that the characteristic F2-layer critical frequency variations can be explained on the basis of a wind shear of the order of 25 to 50 meters per second per 100 kilometers. The wind shear can account for most of the "anomalous" behavior in the Antarctic."

Scientific Report 6, Ionospheric Disturbances Following a Solar Flare, by G. E. Hill, reprinted from J. Geophys. Res. 65, 3183-3207 (1960).

"Northern hemispheric charts of fmin, foEs, and foF2 at intervals of 3 hours have been constructed for the disturbed period from September 12 through 15, 1957. Enhanced fmin values were found over the polar cap on September 12. By the time of the sudden commencement (SC) of geomagnetic activity (0046Z, September 13) the fmin disturbance spread outward to the auroral zone. Following the SC, the fmin disturbance formed in an elliptical ring around the earth while the polar cap fmin disturbance dissipated. The elliptical ring (coincident with constant dip lines) then expanded southward, and by 0900Z, the approximate time of the main phase, the fmin ring disturbance reached a constant dip of about 72°. Just to the north of this ring, in Canada, a crescent-shaped sporadic-E disturbance developed. It also moved southward. Subsequently, a band of sporadic E appeared over northern Asia. The foF2 disturbance began about the time of the SC and lasted about 36 hours.

"On the basis of the fmin and foEs patterns, it is concluded that, prior to the SC, solar corpuscles impinge on the lower ionosphere directly from outside the earth's 'magnetosphere'. The post-SC fmin and foEs disturbances are attributed to trapped radiation drifting at relatively low altitudes (below about 2000 km). The southward expansion of the disturbances is a result of the strengthening of the solar stream."

Scientific Report 7, Spread F, by R. B. Penndorf, Avco RAD-TR-61-1, AFCRL-60-1162 (November 1960), 113 p.

"The report is based on an extensive and original investigation of ionospheric data obtained during the IGY. Following the Introduction, a short summary is given describing the past work on spread F. Scaling of original ionograms leads to a definition of three types of frequency spreading and one type of range spreading. Each type has been subdivided into species. In addition, a spread-F index has been defined.

"Data for six Arctic stations have been rescaled and analyzed. The diurnal variation of frequency spreading, range spreading, spread-F type, spread-F index, foF2, and fxF2 have been determined. Over the Canadian Archipelago spread F occurs throughout the twenty-four-hour period on a magnetically quiet day, although the F region is illuminated. Differences are found between day and night.

"The investigation of the already scaled data and our own experience have led to recommendations for scaling. For many stations the hourly IGY data have been analyzed to determine diurnal and seasonal variations. The most valuable information has been obtained by analyzing data for the northern hemisphere north of sixty degrees on a universal time basis. It has been found that a zone of maximum occurrence of spread F exists, which coincides with the auroral belt. Two maxima are found in the course of a day, one is called the "traveling" maximum, and its center is situated approximately at the point where the midnight meridian crosses the auroral belt. This maximum moves along the auroral belt in the course of a day. A second maximum, called "permanent" maximum, is situated over the Canadian Archipelago and remains there during the day. These two maxima explain all the diurnal and seasonal variations found in the single station analysis.

"Finally, the interpretation of spread-F observations is given. The combination of the horn of the outer Van Allen belt, the nearly vertical magnetic field lines, and the ripple structure of the F region lead to the temporal variations of spread F and its geographic distribution in the polar region. Three ionospheric models are suggested which lead to spread-F echoes; i.e., ripple structure, a blob structure, and a multiple-layer structure. These models may explain the appearance of spread F in the Arctic."

Scientific Report 7 (Addendum), Classification of Spread-F Ionograms, by R. Penndorf, AFCRL-TN-60-1162 (Addendum), reprinted from J. Atmos. Terr. Phys. 24, 771-778 (1962).

"Scaling of original ionograms obtained in the polar regions has lead to a classification scheme for spread-F ionograms. Defined are three types of frequency spreading (spreadish-F, furcated-F, and spurred-F) and one type of range spreading. Each type is subdivided into species. An example is given for the occurrence of each type on a magnetically quiet day at six polar stations. It is found that spreadish-F predominates and is found more often during the daylight hours than at night. The second most frequent type is range spreading which shows up during the night hours."

Scientific Report 8, Reception of WWV and WWVH in Northern Canada, by J. R. Herman and R. B. Penndorf, Avco RAD-TR-61-5, AFCRL-15 (January 1961), 50 p.

"Quiet-day diurnal, seasonal, and latitude variations in reception quality of WWV and WWVH transmissions on six frequencies from 2.5 to 25.0 mc/s at five northern Canadian stations between 45° and 75°N latitude are given. Solar, propagation-mode, and auroral effects of these transmissions are considered. The investigation shows that the orientation of transmission paths with respect to the auroral zone affects reception quality on long paths (WWVH), and reception improves going northward. It appears that a tilt mode of propagation on long paths is possible at a time when sunrise occurs simultaneously near the two end points of the path. On magnetically quiet days, WWV (15.0 mc/s) reception has been possible for all hours of the day regardless of season during sunspot maximum of 1957-1958."

Scientific Report 9, Predicted Performance of a High-Frequency Polar-Communication Network during an Ionospheric Storm, by N. J. Macdonald, R. Penndorf, and G. E. Hill, Avco RAD-TR-61-17, AFCRL-139 (April 1961), 50 p.

"The knowledge of space and time variations of fmin, foEs, and foF2 during periods of intense polar ionospheric disturbances can be used to design an efficient and highly reliable high-frequency polar-middle latitude communication system. Ionospheric data for a September 1957 storm have been analyzed, proving the feasibility of a frequency link-switching technique."

Scientific Report 10, Relation between Ionospheric and Geomagnetic Storms, by G. F. Rourke, Avco RAD-TR-61-15, AFCRL-TN-61-148 (February 1961), 50 p.

"Analysis has been made of the variations of fmin and the horizontal geomagnetic component in a short-time interval preceding and following 21 sudden-commencement (SC) geomagnetic storms. The relative energy levels of the plasma clouds ejected from the sun are estimated from the variations of the geomagnetic field following a sudden commencement. High-energy clouds are found to be associated with the pre-SC increases in fmin and the horizontal component. Post-SC variations in fmin strongly depend on the magnitude of geomagnetic activity. The polar cap absorption and geomagnetic disturbance accompanying the storms of 13 and 29 September 1957 are analyzed in detail."

Scientific Report 11, Effects of Corpuscular Emissions on the Polar Ionosphere following Solar Flares, by G. E. Hill, AFCRL-509, reprinted from J. Geophys. Res. 66, 2329-2335 (1961).

The morphology of two polar absorption events, July 24-25 and September 18-22, 1957, representing different types of ionospheric disturbances, is presented. It was found that in both events the absorption was more intense in the sunlit portion of the polar cap than in the darkened portion by several megacycles, and that following the polar cap absorption event (PCA) of the September storm, strong auroral zone absorption occurred, a geomagnetic storm developed, and the F2 layer critical frequency decreased markedly, whereas following the July PCA none of these additional disturbances appeared."

Scientific Report 12, Small-Scale Polar-Cap Absorption and Related Geomagnetic Effect, by G. F. Rourke, reprinted from J. Geophys. Res. 66, 1594-1595 (1961) (Letter).

Scientific Report 13, Reception of WWV in Arctic during Ionospheric Disturbance, by J. R. Herman and G. E. Hill, Avco RAD-TR-61-33, AFCRL-950 (October 1961), 31 p.

"Reception characteristics of WWV (from 2.5 to 25 mc/s) at five Canadian stations are shown to have regular diurnal, seasonal, latitudinal, and frequency variations on ionospherically quiet days. A detailed comparison of reception quality and ionospheric parameters during a disturbed period shows that conditions on different frequencies and propagation paths are closely related to the morphology of the ionospheric disturbance. On disturbed days, reception of the lower WWV frequencies (from 2.5 to 10 mc/s) in polar latitudes is affected primarily by polar cap and auroral zone absorption, while that of the higher frequencies (from 15 to 25 mc/s) is affected primarily by depressed F2 critical frequencies and sporadic E support."

Scientific Report 14, Geographic Distribution of Spread-F in the Arctic, by R. Penndorf, AFCRL 62-589, reprinted from J. Geophys. Res. 67, 2279-2288 (1962).

"Hourly IGY data have been analyzed to determine the diurnal and seasonal variation of spread F. Results for July and September 1957, are shown on maps. A zone of maximum occurrence of spread F exists that coincides with the auroral belt. Two maxima are found in the course of a day. One, called the "traveling" maximum, has its center approximately at the point where the midnight meridian crosses the auroral belt. This maximum moves along the auroral belt in the course of a day. A second, called 'permanent' maximum, is over the Canadian Archipelago and remains there during the day. These two maxima explain all the diurnal and seasonal variations found in the Arctic."

Scientific Report 15, Diurnal and Seasonal Variation of Spread-F in the Arctic, by R. Penndorf, AFCRL-62-590, reprinted from J. Geophys. Res. 67, 2289-2298 (1962).

"The diurnal and seasonal variation in the occurrence of spread F is investigated for North American stations by means of hourly ionosonde data for the IGY period. Around the magnetic pole only very small diurnal and seasonal variations are found and explained by the existence of a permanent maximum over the Canadian Archipelago (Foxe Basin). To the north of this area small diurnal variations exist during spring and fall months only, and a seasonal variation is noticed. The general level of spread-F occurrence, however, remains so high, that spread-F conditions exist regularly at local noon. For the rest of the Arctic, pronounced diurnal and seasonal variations exist; they are explained by a traveling maximum that moves along the auroral zone."

Scientific Report 16, Polar-Cap and Auroral-Zone Absorption Effects on 2.5-5.0-Megacycle per Second Atmospheric Radio Noise, by J. R. Herman, AFCRL-62-591, reprinted from J. Geophys. Res. 67, 2299-2308 (1962).

"Atmospheric radio noise data on 2.5 and 5.0 mc/s at Enkoping, Sweden, and Thule, Greenland, have been analyzed for 10 polar-cap and auroral-zone absorption events occurring in the years 1958-1960. Results show that the measured noise power is radically depressed during such events. At Enkoping, 'maximum decrease' on 2.5 and 5.0 mc/s ranged from 10 to 36 db and from 6 to 38 db below normal, respectively. The corresponding ranges at Thule were 5 to 24 and 6 to 14 db below normal. Noise amplitude distribution curves are similar in shape for both ionospherically quiet and disturbed periods; on the average, the disturbed-period envelope is about 7 db below normal."

Scientific Report 17, The Generation and Effect of Electrostatic Fields during an Auroral Disturbance, by D. W. Swift, Avco RAD-TM-62-88, AFCRL-62-758 (9 November 1962), 32 p.

"The equations of motion of electrons and ions in the presence of electric, magnetic, and neutral particle velocity fields are derived for conditions which are apt to exist in an auroral arc. The electric field resulting from charge separation is computed. Electron densities, charged particle motion, and electric currents are also computed. It is shown how these computations can account for magnetic bays, electron drifts and electric field fluctuation observed during auroral disturbances. Analytical expressions for electric field strengths and neutral plasma drift velocities are derived."

Scientific Report 18, Polar Cap and Auroral Zone Absorption Events during the First Six Months of IGY, by G. E. Hill, AFCRL-62-937, reprinted from J. Phys. Soc. Japan 17, Suppl. A-I, Internatl. Conf. Cosmic Rays and the Earth Storm (1962).

"Investigation of polar cap absorption events during the first 6 months of the IGY was conducted by the use of world-wide ionosonde data. Synoptic maps of the parameter fmin were constructed at intervals of 3 hours. A great number of auroral zone and polar cap absorption events were found. In this paper,* only the polar cap events are reported. It was noted that in addition to the events reported by riometer techniques, several additional ones were found. Analysis of all these events is made to give the starting and ending times and their relationship to solar flare and radio noise data and geomagnetic observations."

Final Scientific Report, Item 2, Signal Amplitude Analysis of High-Frequency Circuits Crossing the Auroral Zone, by G. F. Rourke and S. C. Coroniti, Avco RAD-TR-62-4, AFCRL-62-106 (7 May 1962).

"Pulsed transmissions at 12 and 18 mc/s from College, Alaska and Thule, Greenland were continuously monitored at Boston, Massachusetts for a period of 9 months. Observed signal amplitudes are graphically presented and discussed for each of these months. Comparisons are drawn between the observed

* A complete list of the polar cap absorption events given in this paper is reprinted in appendix V-B of the present report. The series of fmin maps used to identify these PCA's has not been previously published except for selected examples; thus, the entire series is also presented in appendix V-B.

and predicted values of signal intensity and maximum usable frequency (MUF). The predicted signal intensity was 10 to 20 db higher than the observed signal intensity. The gross effects of the auroral zone on these circuits are discussed and anomalous behavior of the Thule-Boston 18-mc/s circuit near the MUF is presented."

Final Report, Item 3, Medium-Frequency Groundwave Communication over Large Distances during Auroral and Manmade Blackout, by J. R. Herman, Avco RAD-TR-62-2, AFCRL-969 (October 1961).

"The possibility of utilizing the groundwave mode of 1.5 to 3.0 mc/s radio transmission for long-distance (1200 to 1500 miles) ground-to-air communication over seawater to the northward during auroral and manmade blackout is explored. Ionospheric propagation modes are ineffective during such disturbed conditions and only the steady groundwave remains, so that no fading should result. Also, atmospheric radio noise being propagated by ionospheric modes from the principal noise centers of the world is absorbed by the disturbed D region, so that the external noise level at the receiver consists mainly of locally generated noise and is thus radically depressed. It is shown that the depressed noise levels during manmade and auroral blackout are low enough to allow communication with a tolerable error rate by means of groundwaves, due to the fact that the signal-to-noise ratio is effectively increased.

"For example, during the manmade blackout associated with the Johnston Island Teak explosion, the external noise level at Kekaha, Hawaii, dropped to 35 db (about 30 db below normal) which, when coupled with other transmission factors (e.g., signal ground losses), would allow a received signal-to-noise ratio of 6.2 db. With a frequency-shift-keyed (FSK) ± 50-cps system operating with a 30-kw effective transmitter power, a transmitter antenna gain of 15 db, and a ground-based receiver, the error rate corresponding to this signal-to-noise ratio would be about 4 percent.

"Using the same system with the receiver aboard aircraft in flight, the noise external to the antenna in the absence of atmospherics is about 47 db, 12 db higher than the external noise at a ground-based-receiving site. However, the height-gain factor, which is of the order of 10 db at altitudes easily attainable by present-day aircraft, partially compensates for this extra noise. Aboard aircraft in flight, the best signal-to-noise ratio that can be expected is 1.8 db, which, with a FSK ± 50-cps system, will allow an error rate of 13 percent. Height-gain factors for 1.5 to 3.0 mc/s and receiver altitudes of 0 to 50,000 feet at transmission distances of 1200 to 1500 miles are presented."

III. ABSTRACTS OF JOURNAL ARTICLES

Coroniti, S. C. and R. Penndorf, [The] Diurnal and annual variations of foF2 over the polar regions, J. Geophys. Res. 64, 5-18 (1959). (See under Scientific Report 2 for abstract.)

Herman, J. R., Solar-flare effects on 2.5 and 5.0 mc/s atmospheric radio noise, J. Geophys. Res. 66, 3163-3167 (1961). (Based on parts of Final Report, Item 3.)

"Analysis of radio noise records from Kekaha, Hawaii, and Ohira, Japan, during 75 solar flares occurring during August, September, and October 1958, reveals a positive relationship between short-time noise power decreases and solar flares. The most significant noise fadeouts associated with flare eruptions occurred with the sun over one of the major noise centers contributing to the noise level at the measuring station. Maximum noise decrease of 18 db was observed on 5.0 mc/s at Kekaha when the sun was over the East Indies noise center, just after sunset at the receiver."

Herman, J. R., Reliability of atmospheric radio noise predictions, J. Research Nat. Bur. Standards, Radio Propagation, 65D, 565-574 (1961).

"Measured radio noise values are compared with the corresponding International Radio Consultative Committee (C.C.I.R., 1957) predicted values at four noise measuring stations. Five frequencies between 0.013 and 10.0 mc/s are considered. The stations selected for this study include Balboa, Panama, near two major radio noise centers, and Byrd Station, Antarctica, remote from atmospheric radio noise sources. It is found that the predicted and measured noise levels are in good agreement except at some places and times, where large discrepancies occur. Most of the disagreements are found at places where the predictions are based on extrapolations of data measured at other stations. Reasons for the disagreements are discussed."

Herman, J. R., Polar-cap and auroral-zone absorption effects on 2.5-and 5.0-megacycle per second atmospheric radio noise, J. Geophys. Res. 67, 2299-2308 (1962). (See under Scientific Report 16 for abstract.)

Hill, G. E. and J. R. Herman, WWV reception in the Arctic during ionospheric disturbances, J. Research Nat. Bur. Standards, Radio Propagation, 67D 179-182, (1963). (Based on parts of Scientific Report 13).

"Reception of WWV at four high-latitude stations is compared with ionospheric data during a period of severe ionospheric storminess. It was found that the reception quality of WWV closely follows the morphology of the disturbance. Reception at the lower frequencies was affected primarily by the PCA event and auroral-zone absorption, while at the high frequencies reception depended upon the storm-time behavior of the F region. Also, reception was strongly affected for several hours during the storm by the appearance of a large sporadic-E cloud. Despite the fact that reception quality was assessed by aural monitoring, agreement between the reported WWV reception and that which would be expected from the ionospheric data is rather good. It is concluded that the behavior of radio reception can be explained on the basis of the space-time variations in ionospheric parameters."

Hill, G. E., Anomalous foF2 variations in the Antarctic, J. Geophys. Res. 65, 2011-2023 (1960). (See under Scientific Report 5 for abstract.)

Hill, G. E., Ionospheric disturbances following a solar flare, J. Geophys. Res. 65, 3183-3207 (1960). (See under Scientific Report 6 for abstract.)

Hill, G. E., Effects of corpuscular emissions on the polar ionosphere following solar flares, J. Geophys. Res. 66, 2329-2335 (1961). (See under Scientific Report 11 for abstract.)

Hill, G. E., Polar cap and auroral zone absorption events during the first six months of IGY, J. Phys. Soc. Japan, 17, Suppl. A-I, Internat'l. Conf. Cosmic Rays and the Earth Storm (1962). (See under Scientific Report 18 for abstract.)

Hill, G. E., HF communication during ionospheric storms, J. Research Nat. Bur. Standards, Radio Propagation 67D, 23-30, (1963). (Based on Scientific Report 9.)

"A hypothetical communication network is set up to study systematically the problem of HF communications during disturbed ionospheric conditions. Vertical incidence radio data is used as the basis for determining the condition of the ionosphere. Frequencies and links available have been computed for a period of severe ionospheric disturbance. Important spatial and temporal variations are clearly evident by this analysis. A comparison of the results with recorded WWV reception indicates that ionospheric vertical incidence data can be used to determine propagation conditions during disturbed periods."

Penndorf, R. and G. E. Hill, The absorption effect in the arctic during a severe ionospheric storm, J. Atmos. Terr. Phys. 23, 191-201 (1962).

"A complete set of ionospheric data for the northern hemisphere has been analyzed for September 11-14, 1957, during a period when a severe ionospheric and magnetic storm occurred. Synoptic charts were constructed at three-hour intervals for fmin, foEs, and foF2. The analytical method used allowed the transformation of blackout data into fmin data, so that reliable charts of equal fmin could be obtained.

"About 20 hours after the occurrence of a solar flare, fmin started to increase over the polar cap. With time, these values increased steadily to about 7 mc/s with highest values near the pole. This increase -- leading to blackout conditions at several inner Arctic stations -- lasted for somewhat over 24 hrs. (Polar Cap Absorption - PCA.)

"At the time of the Sudden Commencement, a steep gradient of fmin occurs as a ring along the auroral zone. This gradient of 3-4 mc/s is confined to a width of a few hundred kilometers.

"After the Sudden Commencement, i. e. during the main phase of the storm, fmin decreased over the inner Arctic so that normal values of about 2 mc/s were found 8 hours after the SC. However, a ring of high values prevailed during the main phase, first along the auroral belt, then moving southward towards a dip angle of about 71°."

Penndorf, R. and S. C. Coroniti, Polar Es, J. Geophys. Res. 63, 789-802 (1958). (See under Scientific Report 1 for abstract.)

Penndorf, R. and S. C. Coroniti, Propagation of HF and VHF in the arctic region, IRE Trans. Comm. Sys. CS-7, 121-125 (June 1959). (See under Scientific Report 4 for abstract.)

Penndorf, R., A spread-F index, J. Atmos. Terr. Phys. 24, 543-545 (1962). (Based on parts of Scientific Report 7.)

"Present scaling methods for vertical incidence ionograms indicate only that spread-F conditions exist, without differentiating the degree of spreadiness. A spread-F index is introduced which is based on the frequency spread, in units of 0.1 mc/s. The index clearly reveals the severity of spread-F as well as its diurnal variation, which does not show up in analysis of the descriptive letter F in the data sheets. It is concluded that the new spread-F index is useful for studying time variations of the phenomenon and correlating with other phenomena such as radio star scintillation."

Penndorf, R., Classification of spread F ionograms, J. Atmos. Terr. Phys. 24, 771-778 (1962). (See under Scientific Report 7 Addendum for abstract.)

Penndorf, R., Geographic distribution of spread-F in the arctic, J. Geophys. Res. 67, 2279-2288 (1962). (See under Scientific Report 14 for abstract.)

Penndorf, R., Diurnal and seasonal variation of spread F in the arctic, J. Geophys. Res. 67, 2289-2298 (1962). (See under Scientific Report 15 for abstract.)

Penndorf, R., Spread F over the polar cap on a quiet day, J. Geophys. Res. 67, 4607-4616, (1962). (Based on Scientific Report 7.)

"Ionograms for six arctic stations have been scaled and analyzed. The diurnal variation of frequency spreading, range spreading, spread-F type, spread-F index, foF2, and fxF2 have been determined. Over the Canadian Archipelago spread F occurs throughout the 24-hour period on a magnetically quiet day, even though the F region is illuminated. Differences are found between day and night. The diurnal variation of the severity of spread F can best be followed by means of the type of spread F and its index."

Rourke, G. F., Small-scale polar-cap absorption and related geomagnetic effect, J. Geophys. Res. 66, 1594-1595 (1961). (See under Scientific Report 12 for abstract.)

Rourke, G. F., Minor PCA events during March 1958, J. Geophys. Res. 66, 4316-4318 (1961).

"PCA events occurring on March 11 and 14-15, 1958, are discussed on the basis of synoptic fmin analysis. The first event was of small magnitude and absorption was strongly influenced by the sunrise line, but it was followed by a geomagnetic sudden commencement and main phase storm just as with many large PCA's. The March 14 event was followed by a sudden commencement but no geomagnetic main phase storm. It is shown that the association between these ionospheric disturbances and geomagnetic variations is of similar geophysical significance as that for severe disturbances."

Swift, D. W., The generation and effect of electrostatic fields during an auroral disturbance, J. Geophys. Res. 68, in press (April 1963). (See under Scientific Report 17. for abstract.)

IV. LIST OF SYMPOSIUM PAPERS

Herman, J. R., Groundwave Communication during Auroral Blackout, 7th Nat'l. Comm. Symp., Utica, N. Y. (2-4 October 1961).

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Hill, G. E., Results of Critical Frequency Studies for the Northern Hemisphere, Ann. Spring Mtg., URSI, Washington, D. C. (7 May 1959).

Hill, G. E., Anomalous foF2 Variations in the Antarctic, Ann. Spring Mtg., URSI, Washington, D. C. (2-5 May 1960).

Hill, G. E., Ionospheric Disturbances following a Solar Flare, Ann. Spring Mtg., URSI, Washington, D. C. (2-5 May 1960).

Hill, G. E., Avco Natural Communication System, 5th Nat'l. Symp. Global Comm., Chicago (22-24 May 1961).

Hill, G. E., Polar Cap and Auroral Zone Absorption Events during the First Six Months of IGY, Internat'l. Conf. Cosmic Rays and the Earth Storm, Kyoto, Japan (4-15 September 1961).

Hill, G. E., HF Communication during Ionospheric Storms, Ann. Spring Mtg., URSI, Washington, D. C. (30 April-3 May 1962).

Penndorf, R. and G. E. Hill, The Absorption Effect in the Arctic during a Severe Ionospheric Storm, 5th AGARD-Ionospheric Res. Comm. Mtg., Athens, Greece (June 1960).

Penndorf, R., Spread F in the Polar Region, Ann. Spring Mtg., URSI, Washington, D. C. (2-5 May 1960).

Penndorf, R., Diurnal Variation of Spread F, Fall Mtg., URSI, Boulder, Colo. (2-5 December 1960).

Penndorf, R. and S. C. Coroniti, Propagation of HF in the Polar Regions, IRE-PGCS, 4th Nat'l. Aerospace-Comm. Symp. Utica, N. Y. (October 1958).

Penndorf, R., S. C. Coroniti, and G. E. Hill, Northern Hemisphere Charts of foF2, Ionospheric Soundings in the IGY/IGC-URSI, Nice, France (11-16 December 1961).

Penndorf, R., S. C. Coroniti, and G. E. Hill, Synoptic Charts During Ionospheric Storms, Ionospheric Soundings in the IGY/IGC-URSI, Nice, France (11-16 December 1961).

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V. APPENDIXES

A. ANOMALOUS ABSORPTION AT HIGH LATITUDES -- A BIBLIOGRAPHY (J. R. Herman)

B. SYNOPTIC CHARTS OF fmin (G. E. Hill)

A. ANOMALOUS ABSORPTION AT HIGH LATITUDES--A BIBLIOGRAPHY

(J. R. Herman)

One of the major causes for high-frequency (HF) radio-communication failure in high latitudes is the occurrence of anomalous absorption of radiowaves by enhanced ionization in the D region. Because such events occur fairly often (3 to 4 times a month on the average during high sunspot years) and may last for several days, the importance of their study to polar communications is obvious. A rather extensive bibliography on polar absorption and related phenomena has been collected in connection with our own work, so it is felt useful to present it here for future reference. Also, it is appropriate to summarize the major features of the characteristics and causes of anomalous absorption at high latitudes.

Early statistical studies by Agy (1954) revealed that the regions of high absorption may cover large areas and last for several days, but they led to the unexpected conclusion that the absorption duration increases with increasing latitude. Bailey (1957) seems to have been one of the first to recognize the existence of two types of absorption; i.e., one of which is associated primarily with the auroral zone, while the other, commonly referred to as polar cap absorption (PCA), occurs at higher latitudes near the poles ($\gtrsim 70°$ geomagnetic latitude). Bailey's observation, which explained Agy's earlier finding, was soon confirmed by Hakura, Takenoshita, and Otsuki (1958), and Reid and Collins (1959). Reid and Collins further suggested that the causal mechanisms were different for the two types of absorption.

Since much of the knowledge of anomalous absorption is still expressed in terms of the measuring techniques employed, a brief description of them is presented. The principal radio techniques which have been used are as follows:

a. Field-strength variations of very-high-frequency (VHF) radiowaves obliquely scattered from the lower ionosphere,

b. Minimum frequency (fmin) reflected vertically from the ionosphere recorded with vertical incidence ionosondes, and

c. Relative field strength variations of cosmic radio noise received on riometers.

VHF has been used mostly in the 30 to 40 mc/s range, while ionosondes are important in the 1 to 15 mc/s range. Riometers are fixed frequency instruments employed primarily between 27 and 50 mc/s, with a few being operated at 18 mc/s. Because each technique supplies somewhat different information, utilization of all three gives a more complete picture of the absorption events.

The principal advantage of the VHF technique (Bailey, 1957, 1959, 1962) is that it is insensitive to auroral zone absorption because the scattering region is below the height at which most such absorption occurs. Also, it is not affected by solar radio noise, which sometimes obscures the absorption effects in riometer measurements. The received signal intensity is independent of frequency because the affecting absorbing region is at a low altitude (~50 km) where the electron collision frequency is much greater than the wave frequency. The signal intensity varies directly with the ambient electron density in the scattering inhomogeneities. Thus, enhanced signal strength means increased ionization at the scattering level (65 to 85 km), and depressed signal strength means increased ionization at the absorbing level ($\gtrsim$ 45 km). Accurate onset times and durations of enhanced absorption are provided by the VHF technique.

A wide network of vertical incidence ionosondes has been established at high latitudes (north and south), making fmin especially valuable for studying synoptic variations in absorption. Increased fmin is indicative of enhanced absorption, so by plotting simultaneous observations from many stations on polar-projection maps (see appendix V-B), the geographical extent and orientation of the absorption can be determined (Hill, 1960, 1961; Obayashi and Hakura, 1960c; Penndorf and Hill, 1962). In the ionosonde frequency range, most of the absorption occurs at altitudes $\gtrsim$ 80 km, thus high fmin and ionogram "blackout" (i.e., fmin >foF2) are complementary to enhanced VHF signals. Patterns of fmin and their time variations can often be used to separate auroral zone and polar cap absorption.

Riometers (Little and Leinbach, 1958; Reid and Leinbach, 1959, 1962; Reid, 1961) measure total absorption through the ionosphere and are, therefore, sensitive to both types of abnormal absorption. They are capable of providing accurate and quantitative measurement of the absorption intensity. Riometer records have shown that auroral zone absorption is highly irregular, while PCA does not vary much with time (Reid and Collins, 1959). By comparing observations on different frequencies, it is possible to estimate the height of the absorbing region. An extensive review of various results obtained from riometer measurements has been reported recently by Hultqvist (1962).

The main features of high-latitude absorption events determined by observations with the foregoing techniques can be summarized as follows:

1. <u>Auroral Zone Absorption</u>

Auroral zone absorption occurs over a wide range of latitudes, and is predominately a nighttime effect (Agy, 1954; Reid and Collins, 1959). As previously mentioned, riometer records indicate that its intensity is highly irregular, which is corroborated by rapid changes in fmin. This type of absorption is associated with geomagnetic storms and visual aurora, but its maximum intensity is reached most frequently several hours after the time of peak magnetic activity (Agy, 1962). The region of absorption is relatively small, being approximately several hundred kilometers in extent, and the fmin patterns show rapid and violent geographic variations. It appears that auroral zone absorption takes place mostly above about 85 km (Bailey, 1962).

2. Polar Cap Absorption

Polar cap absorption begins within a few hours after the occurrence of a major solar flare, starting near the pole and quickly spreading equatorward until most of the polar cap is covered. Both polar caps are usually affected by a PCA (Jelly, 1962; Besprozvannaya, 1962), but some small events are observed in the sunlit polar cap only (Bookin, 1962; Hill, 1962). The lower boundary of PCA has been measured at geomagnetic latitudes as low as 58.5°N and 54°S (Bookin, 1962). From this, it is obvious that the polar cap type can become superposed on auroral zone absorption. Riometer (Reid and Leinbach, 1959) and VHF (Bailey, 1959, 1962) measurements indicate that the intensity is remarkably constant over long periods of time, in contrast to the irregular behavior of the auroral zone type, and the event may last for 1 to 6 days. Most of the absorption apparently takes place between 45 and 75 km (Bailey, 1962), and is most intense and widespread on the sunlit side of the polar cap (Jelly, 1962; Hill, 1961). PCA is not correlated with magnetic activity although nearly all events are followed about 20 hours later by a storm sudden commencement (SSC) and geomagnetic storm (Hakura and Goh, 1959; Rourke, 1961a).

The main features of PCA can be explained by assuming that the ionosphere is ionized by fast protons (approximately 150 mev) emitted from the sun after a major flare (Hultqvist, 1959; Reid and Collins, 1959; Obayashi and Hakura, 1960c). The protons reach the earth within a few hours after the flare and bombard the earth at the polar caps, penetrating to altitudes of 50 km and less. On the other hand, auroral zone absorption is due to ionization caused by lower energy protons (about 10 mev) which reach the earth 18 to 36 hours after the flare and do not penetrate so deeply into the ionosphere. It has been suggested alternatively that auroral zone absorption is caused by precipitation of stored particles from the Van Allen belt (Penndorf and Hill, 1962).

Studies of related phenomena, such as low-energy cosmic-ray increases (Anderson et al, 1959) and solar X-ray enhancements at high altitudes (Winckler et al, 1959), tend to verify theories of polar absorption based on ground-level observations. Further studies at high altitudes using rockets and satellites should result in a complete, and final, understanding of PCA and auroral zone absorption.

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B. SYNOPTIC CHARTS OF fmin
(G. E. Hill)

In the table reprinted from Scientific Report 18, a list is given of the PCA events covered by the fmin maps contained in this appendix. A complete analysis and discussion of the events have been given in the cited report and will not be repeated. Because only selected examples have been published in previous Avco RAD reports, it is felt that the entire map series should be made available here for possible future studies.

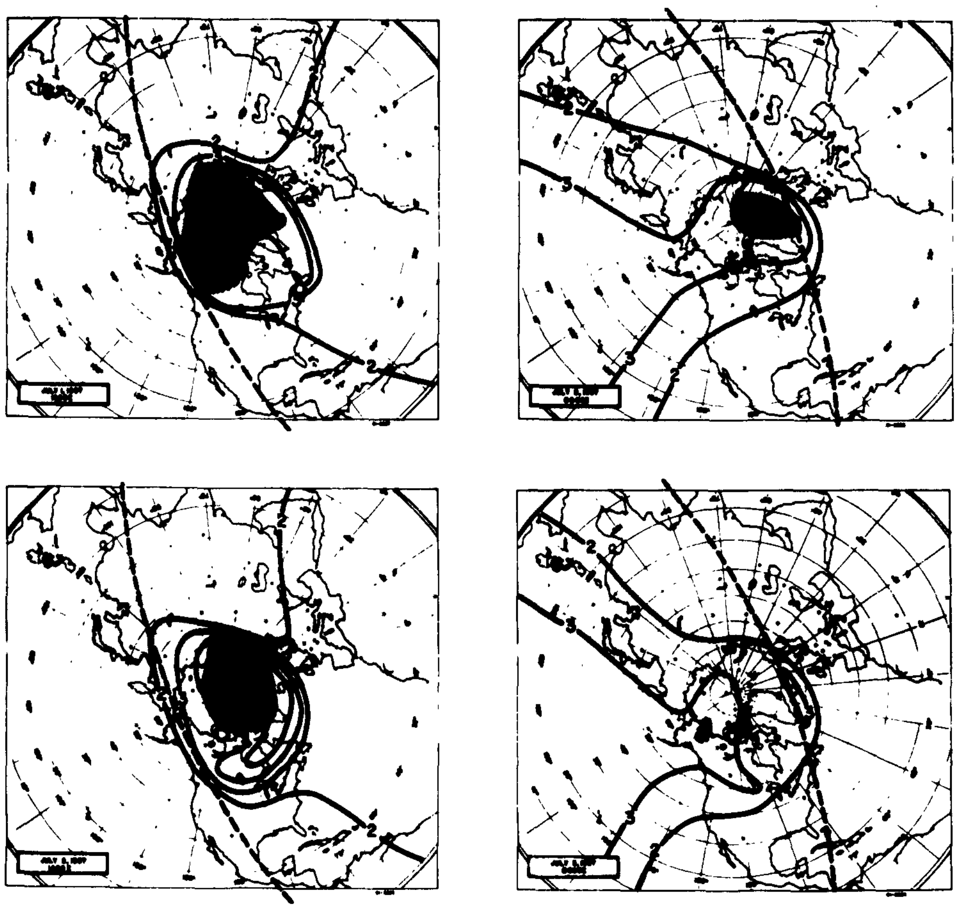
The lowest frequency (fmin) which is recorded by vertical incidence ionosondes is used as a measure of absorption. Values of fmin at a given time which are recorded at stations throughout the northern hemisphere are plotted on the maps, and then isopleths are drawn through equal values at 1-mc intervals. Some smoothing is done to allow for differences in equipment characteristics between stations. The dashed line on the maps represent the twilight line. Charts have been constructed at 3-hour intervals for all PCA's occurring in the 6-month period (July to December 1957). However, the reproduction of all charts for a given disturbance would in many cases be repetitious because the time constant of synoptic changes is often greater than 3 hours. Therefore, it is believed that the maps presented in the following pages adequately represent the absorption-pattern variations for the different events.

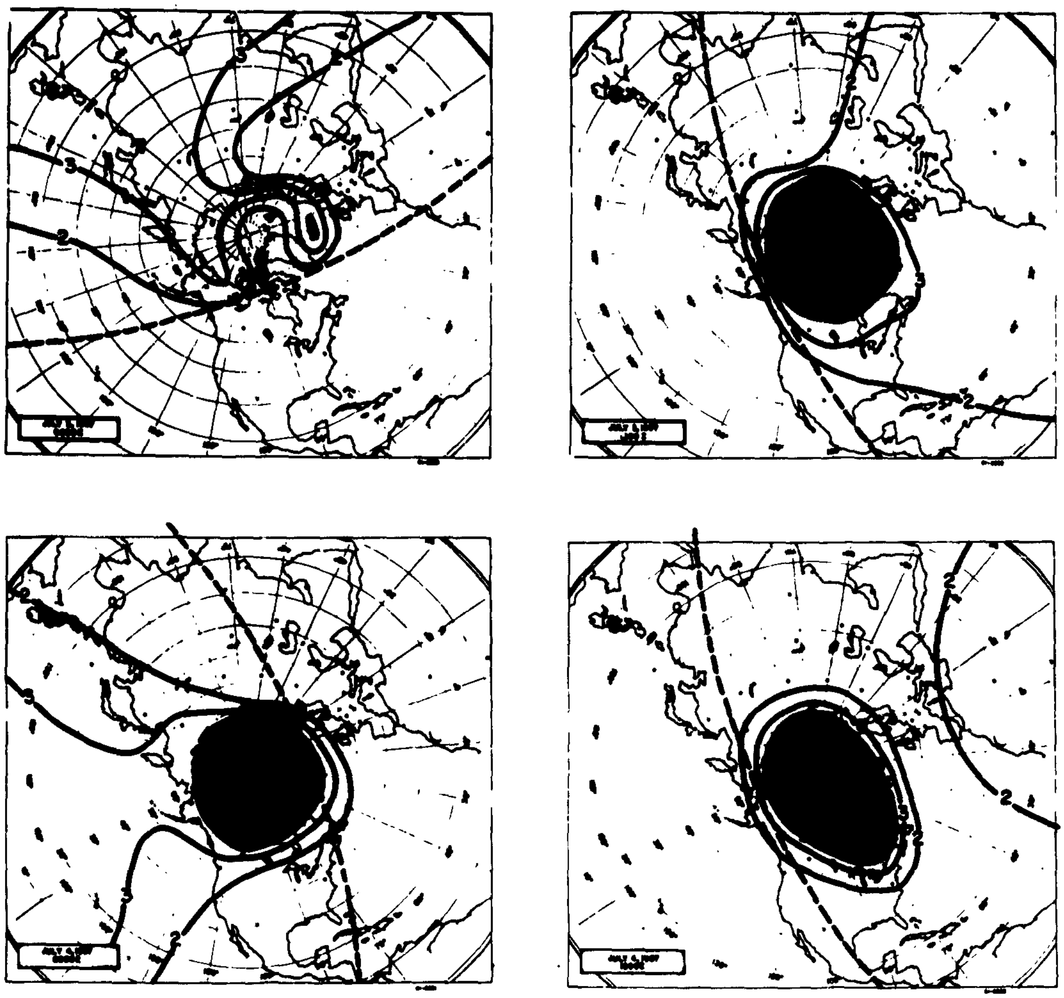
LIST OF PCA EVENTS DURING THE FIRST SIX MONTHS OF IGY

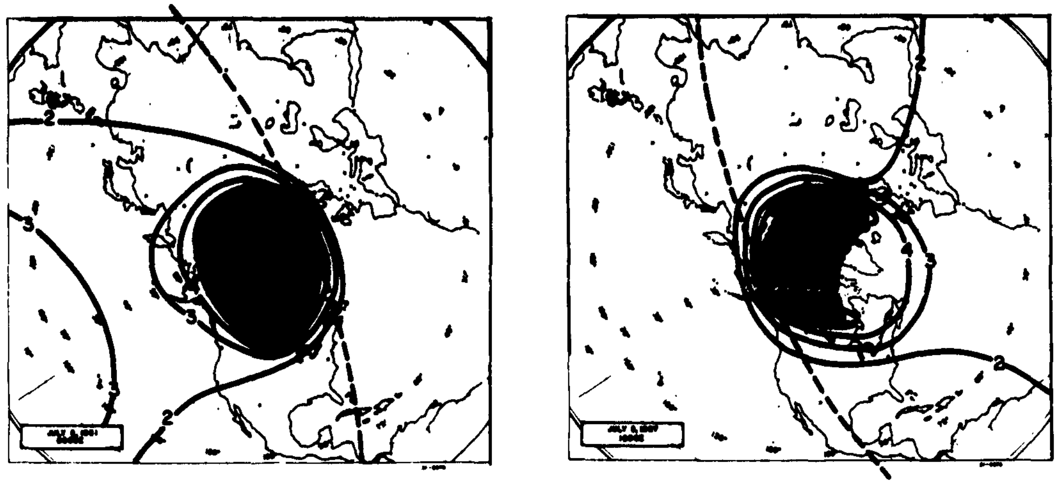
PCA							Flare			Solar Radio Noise (mc/s) $(10^{-22}\ WM^{-2}(c/s)^{-1})$			
Month	Day	Onset	Intensity	Duration <12	12-24	>24	Start	Imp.	Position	10000 to 3000	3000 to 1000	1000 to 450	450 to 80
Jul	1	<00	B*			X	Pre IGY						
	3	09	B			X	3/0712	3+	N14 W40	M 600	M 585	L >282	M (700)
							3/0830	3+	N10 W42	L 2380	M 8200	L 5200	S 3400
	25	00	5		X		24/1712	3	S24 W27	M 336	S 352	--	--
							24/1801	3	S24 W27	--	L 1275	L 1700	M 1000
	28	15	5		X		--						
							Prominence						
Aug	10	00	B			X	(9/1530)	3+	S29 W90				
	28	21	B			X	28/0913	3	S31 E33	--	--	( )	( )
							28/0913	3	S31 E33	L 693	M 1192	M >99	M 106
	31	15	B			X	31/1257	3	N25 W02	L >900	L 3900	L >8500	M >1400
							31/1338	2+	N12 W02	L >900	L <3900	L >14000	L >1400
Sep	2	19	B		X		2/1313	2+	S34 W36	--	--	L 360	--
							2/1313	2+	S34 W36	--	L 304	--	L 3000
	3	15	B			X							
	10	06	4	X			--						
	12	09	B		X		11/0236	3	N13 W02	L 584	L 604	M >30000	M 520
	19	03	4			X	18/1722	3+	N23 E08	--	--	--	--
							18/1818	3+	N20 E03	--	M L 275, 92	L 980	L 2000
	20	03	6		X								
	21	15	B			X	21/1330	3	N10 W06	L 1095	M 785	M 600	S 4000
							21/1440	2	N08 W22	L --	M 200	L 160	--
	22	12	B			X							
	26	21	6			X	26/1907	3	N22 E15	--	L 67	L 450	L >4000
Oct	5	03	5	X			--						
	21	00	7			X	20/1637	3+	S26 W45	--	--	--	--
							20/1644	3+	S26 W35	--	M(L) 4000	M >14000	L >3700
Nov	5	03	7		X		--						
	26	12	4	X			24/0848	3	S14 E37	L 543	M >998	L 210	L >50000
			B S. H.				24/1100	3	S12 E35	M 313	S 179	S 240	--
Dec	17	03	4			X	--						
	29	00	--	X			--						
			5 S. H.										

*B=Blackout; L=Duration greater than 60 minutes; M=Duration between 10 and 60 minutes; S=Duration less than 10 minutes.

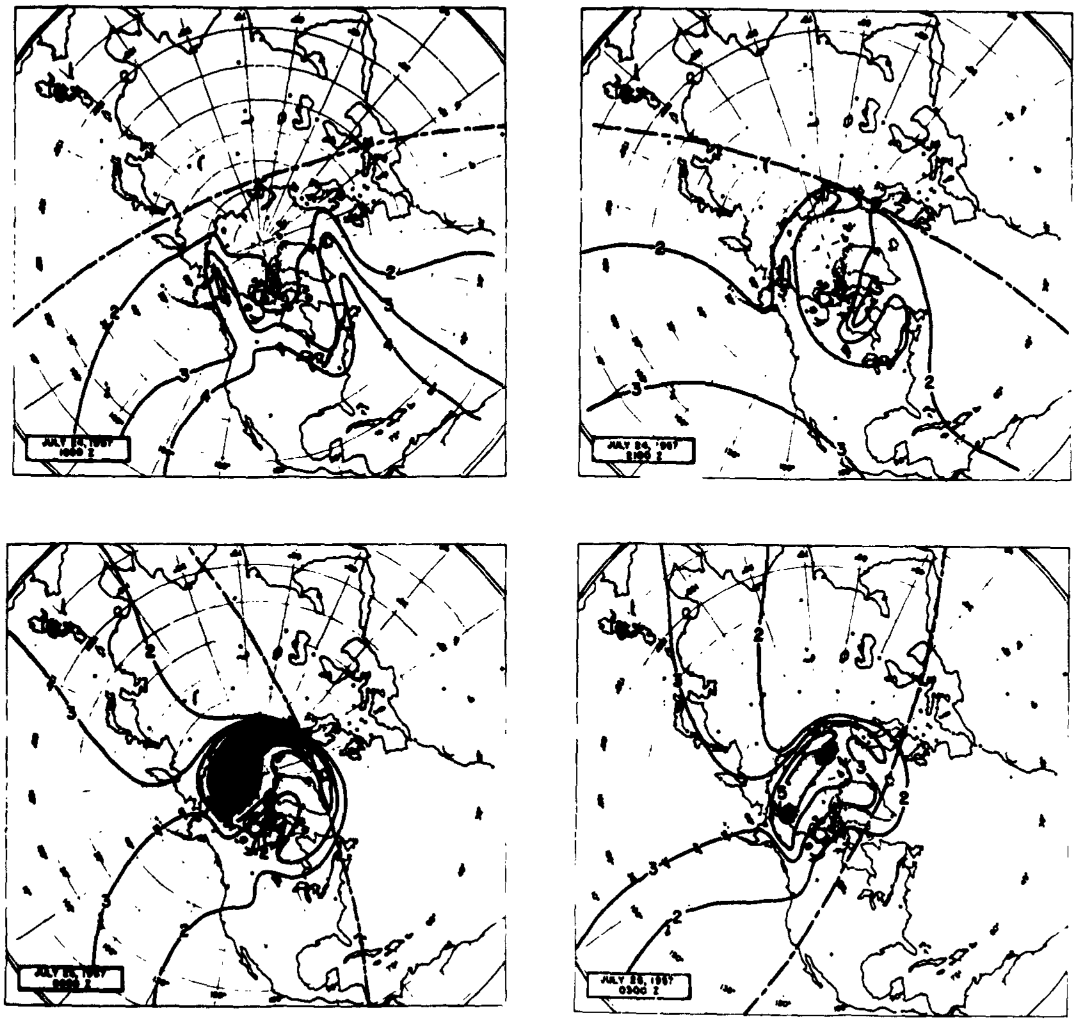
SYNOPTIC fmin CHARTS FOR 1-5 JULY 1957







SYNOPTIC fmin CHARTS FOR 24-25 JULY 1957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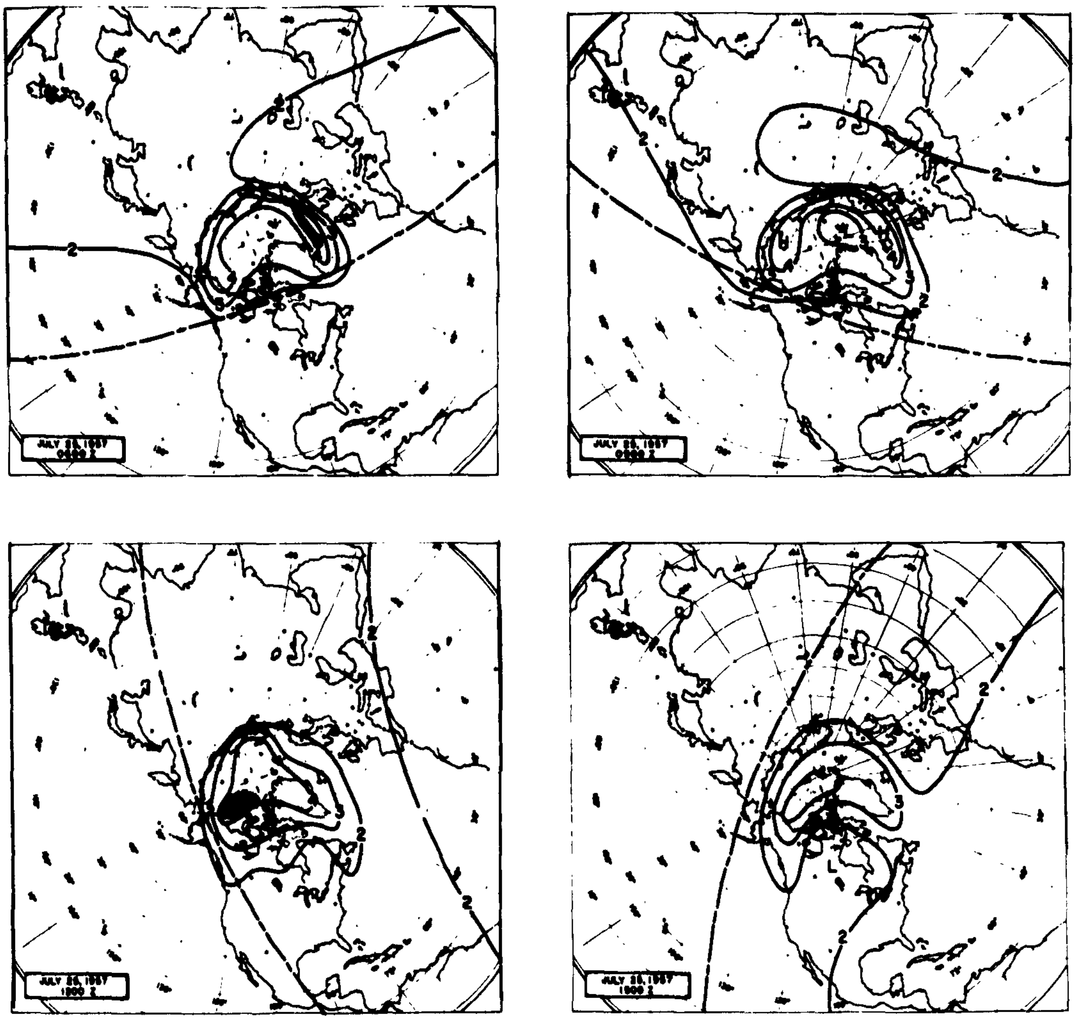
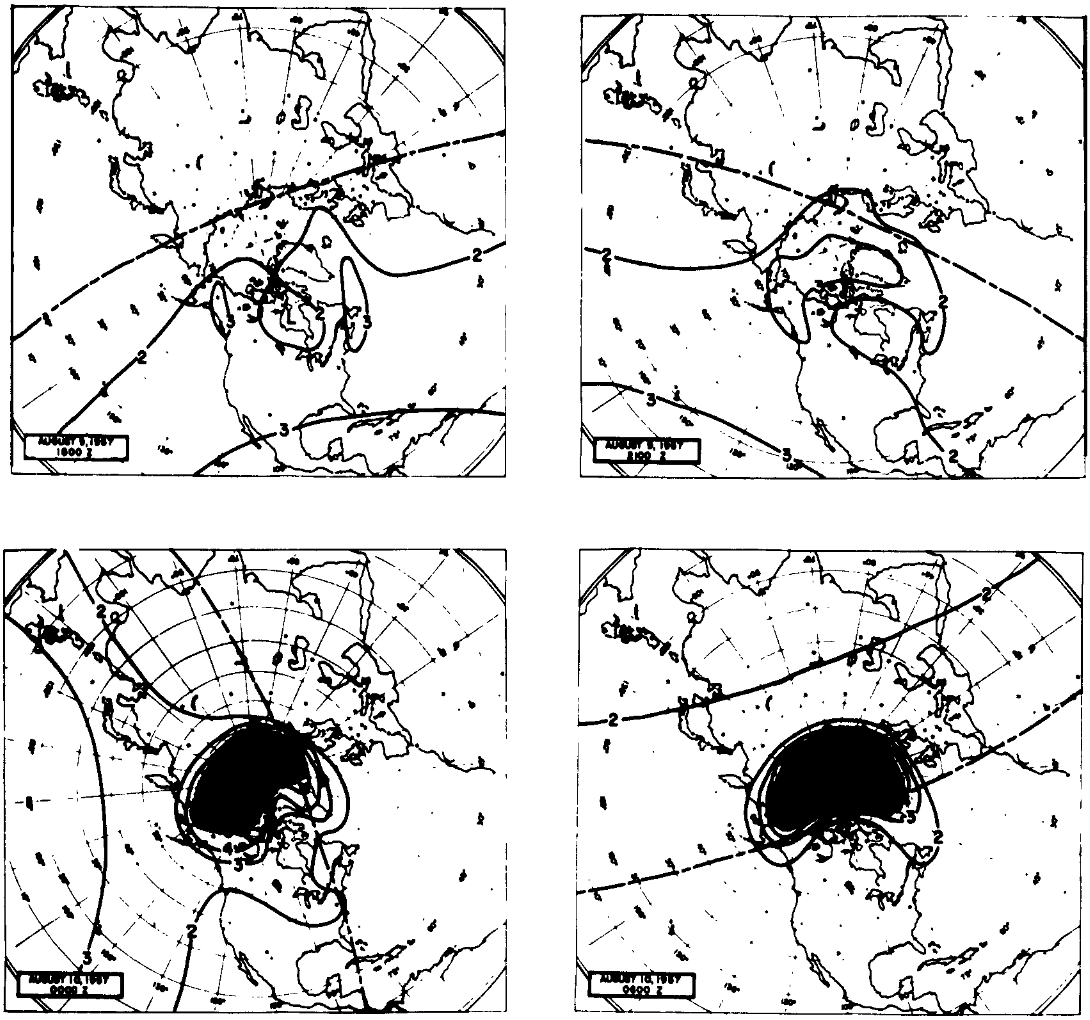
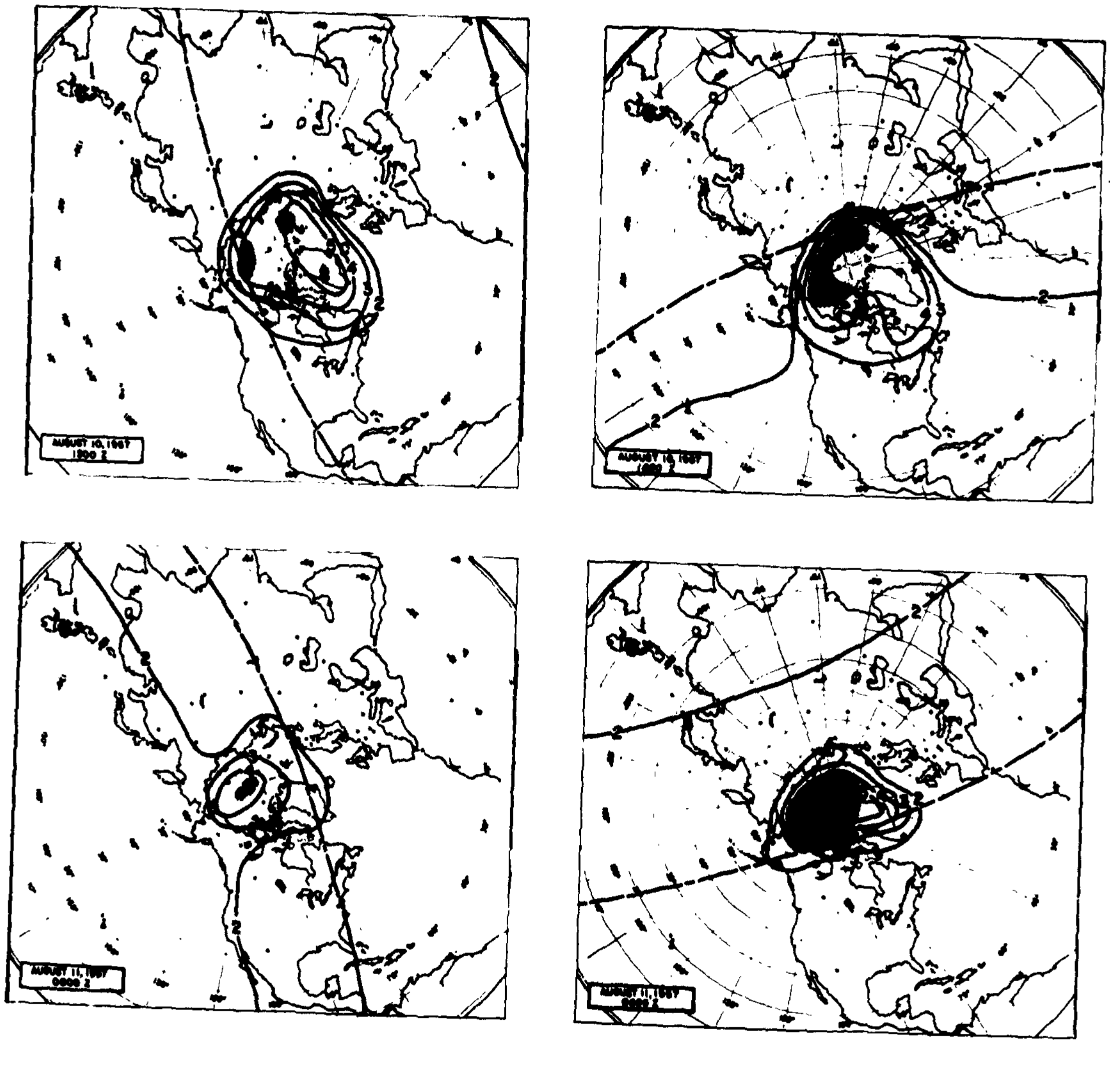


SYNOPTIC fmin CHARTS FOR 9-13 AUGUST 1957

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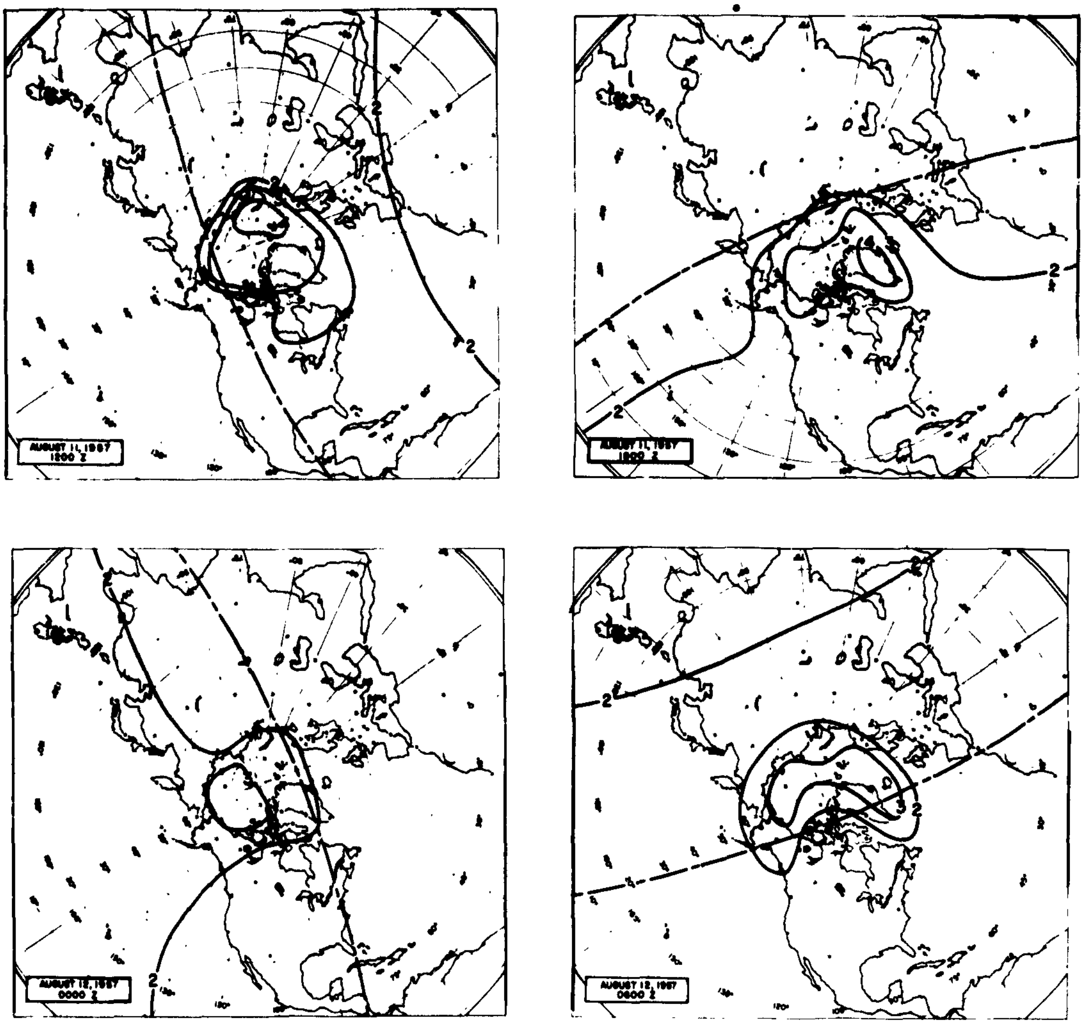
AUGUST 11, 1967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AUGUST 12, 1967
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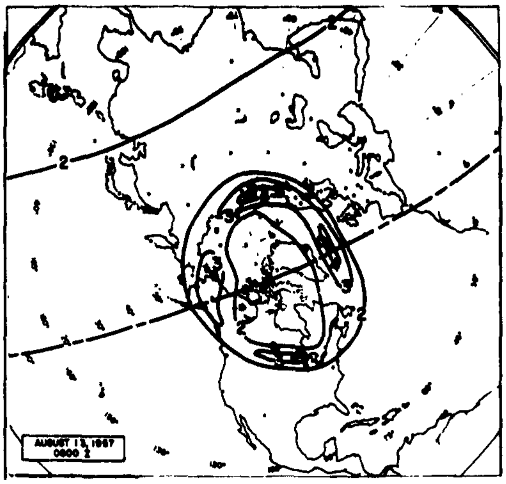
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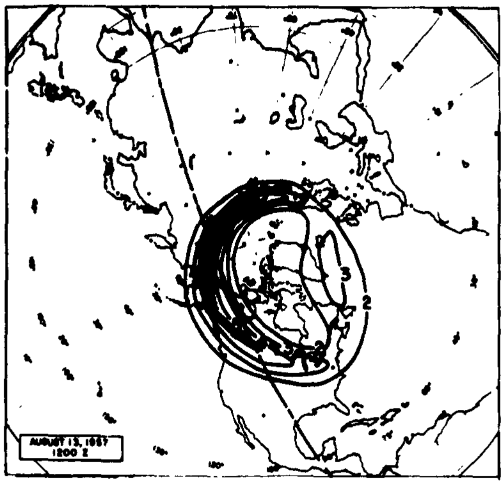
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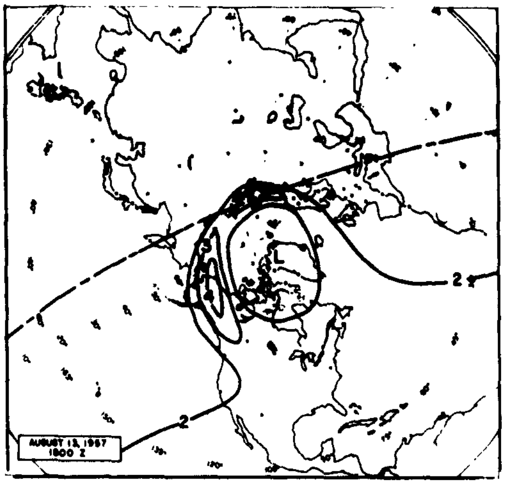
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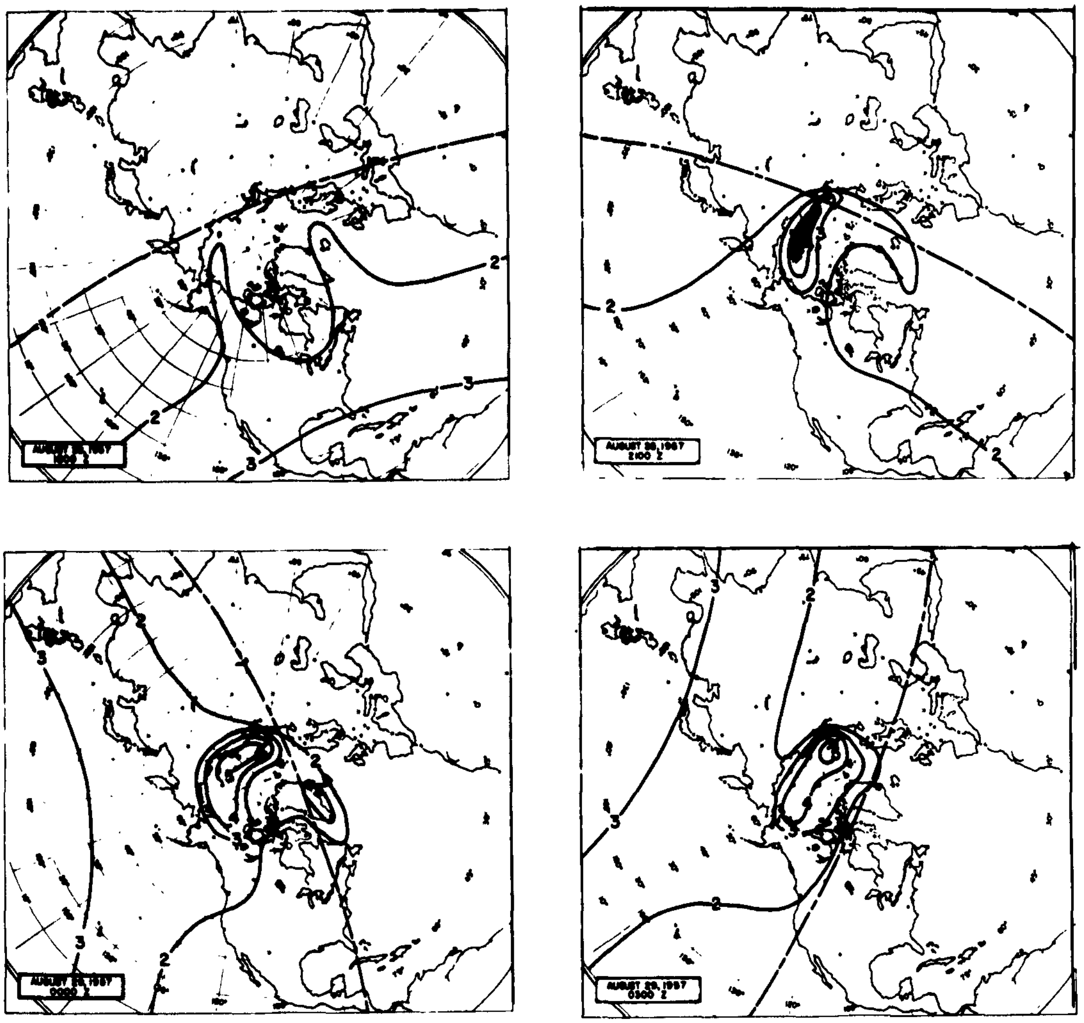
SYNOPTIC fmin CHARTS FOR 28 AUGUST - 4 SEPTEMBER 1957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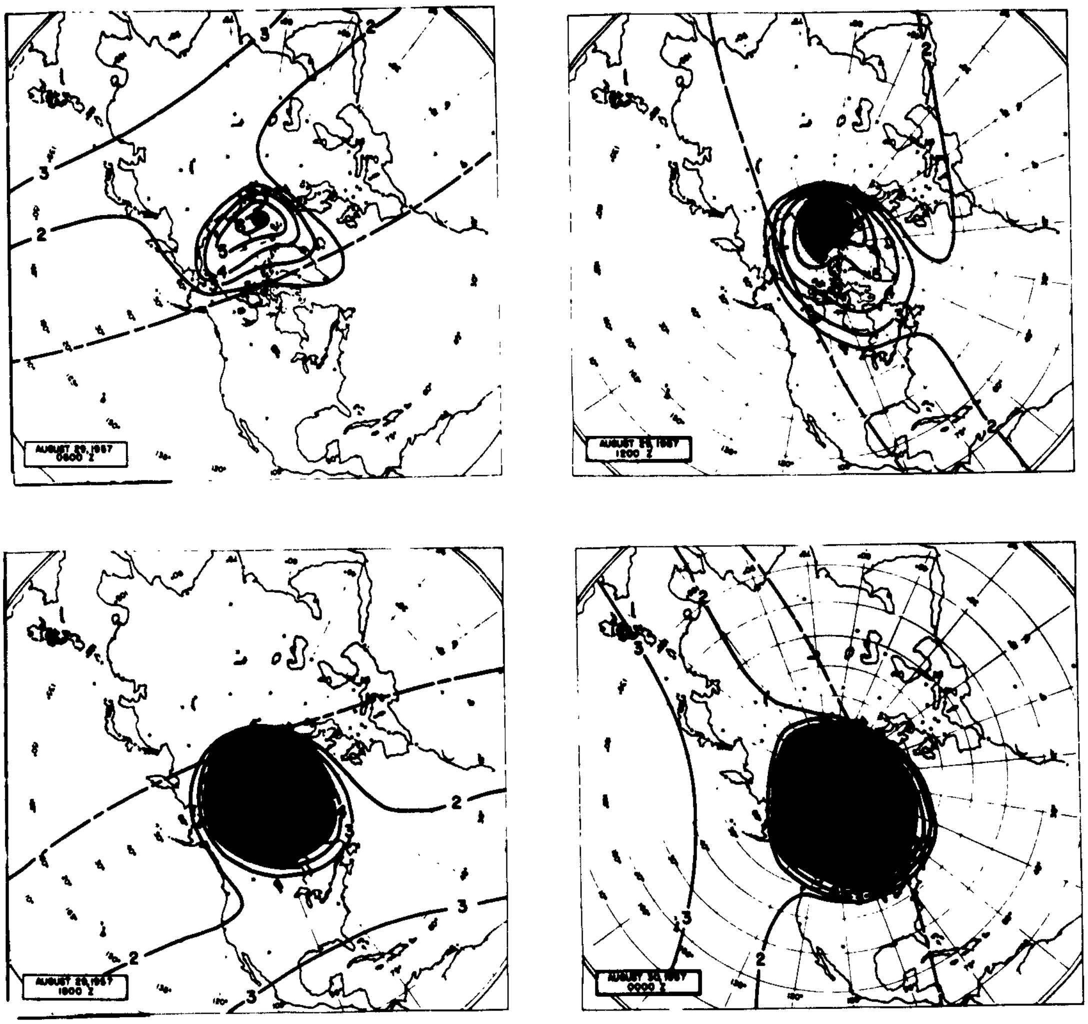
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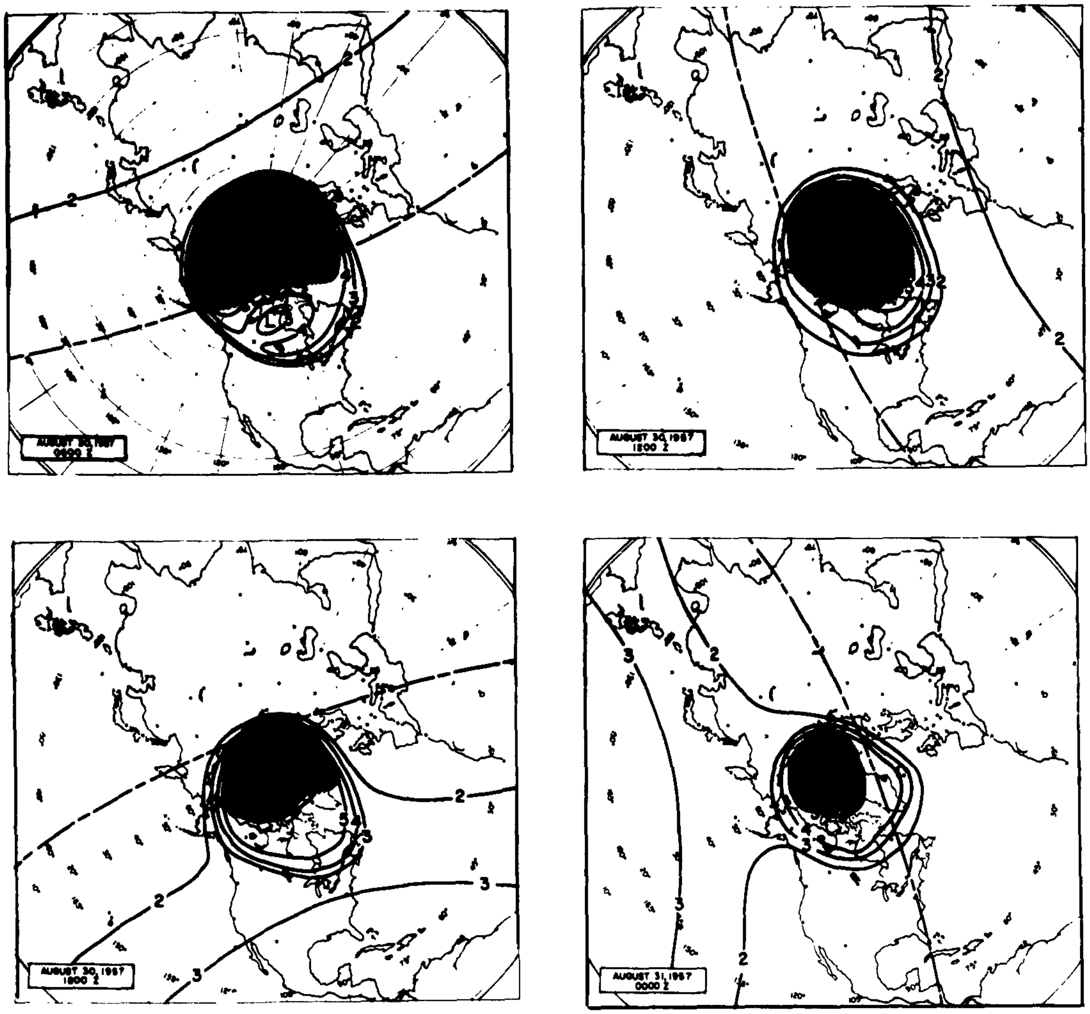
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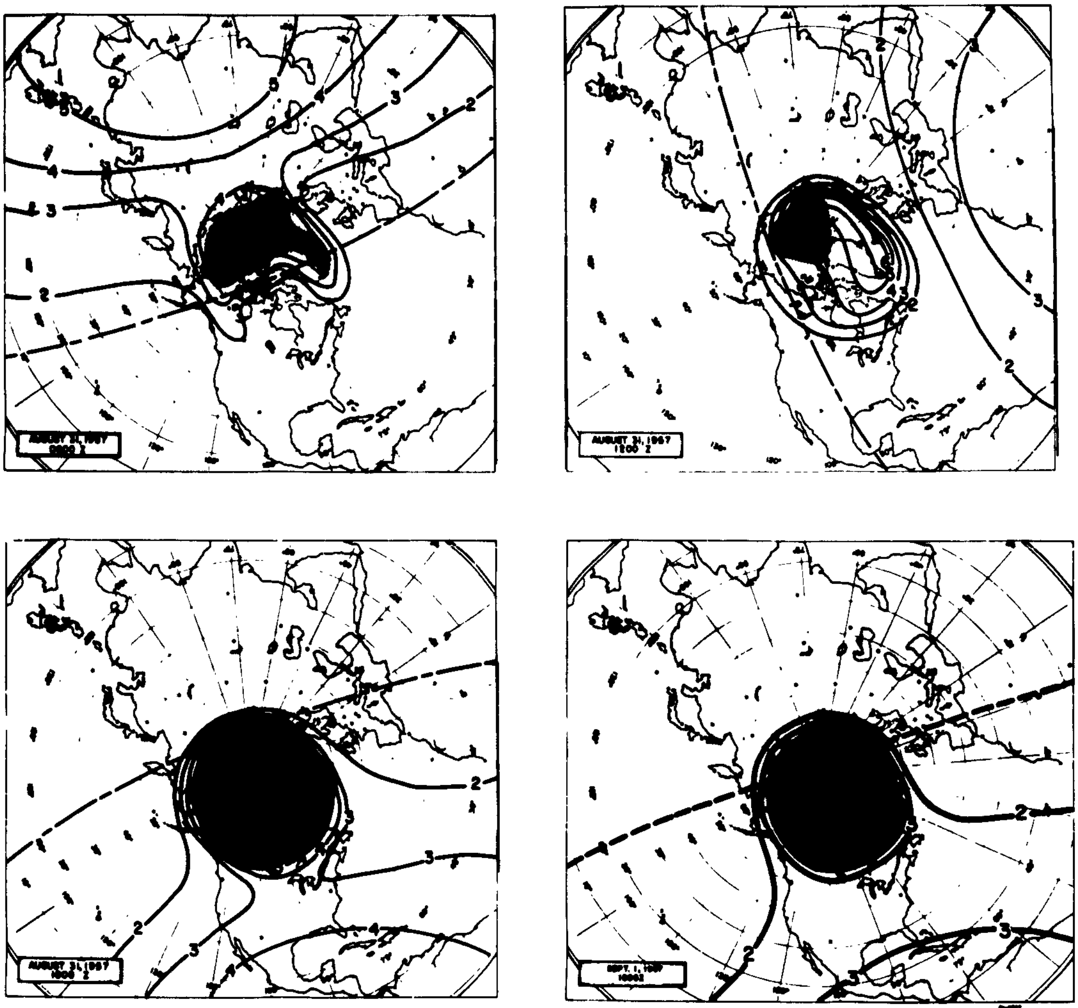
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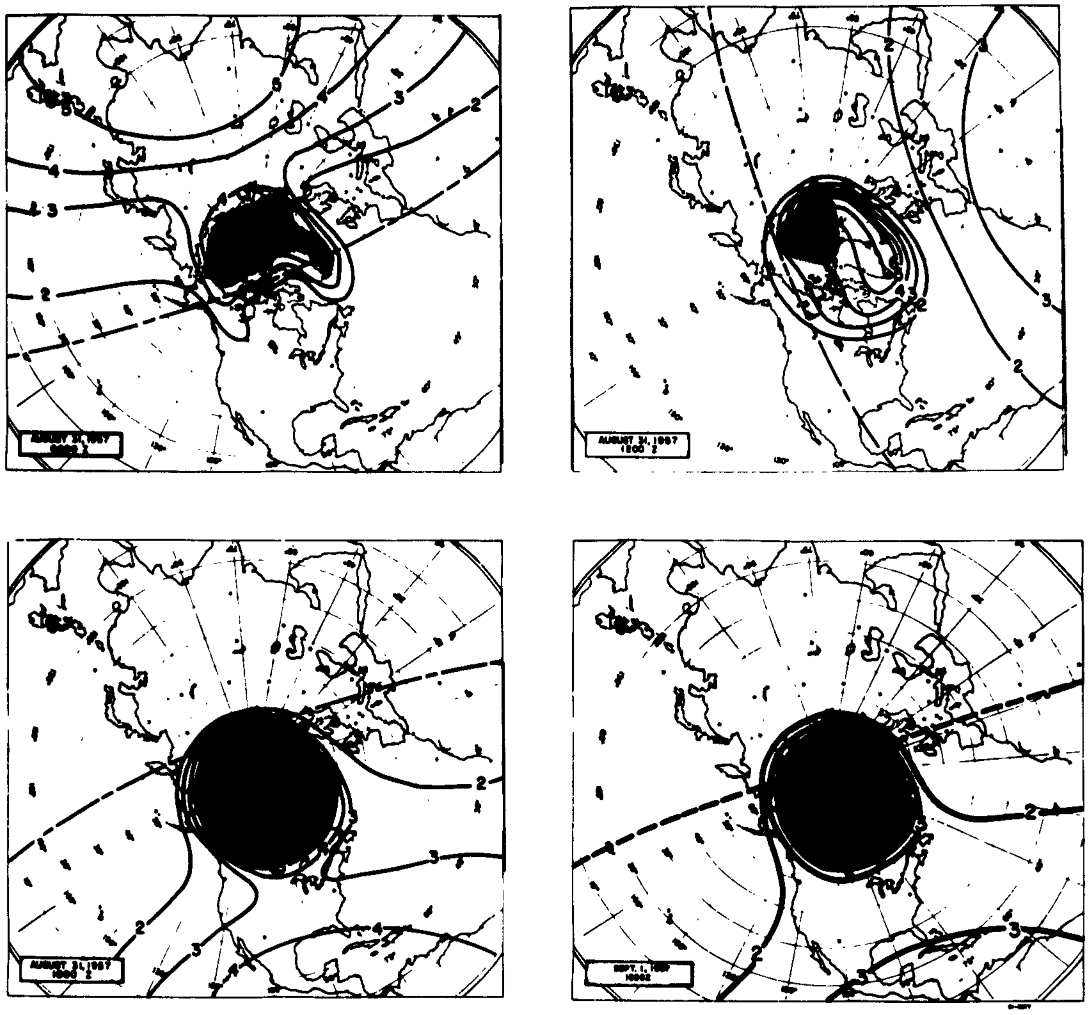
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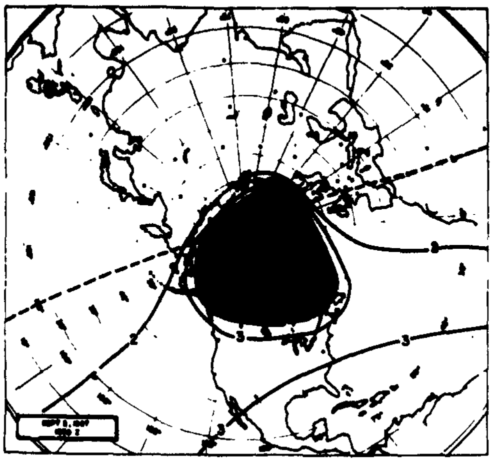
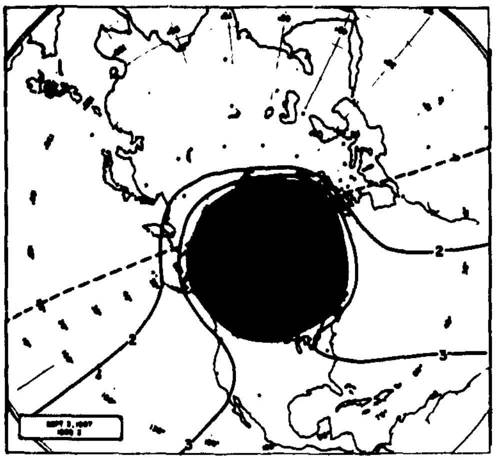
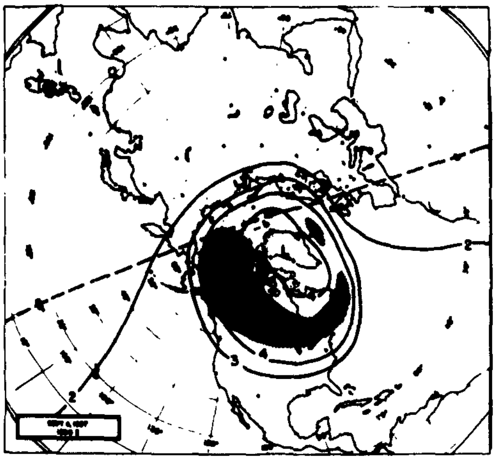
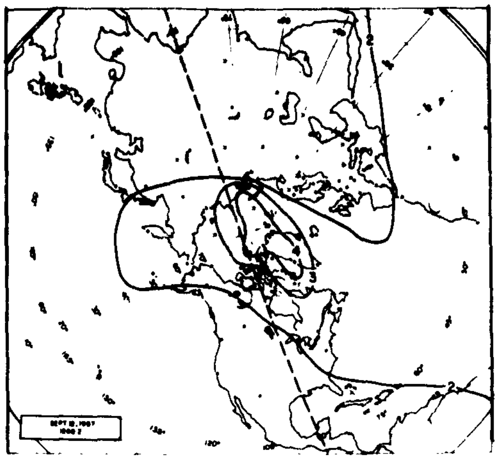
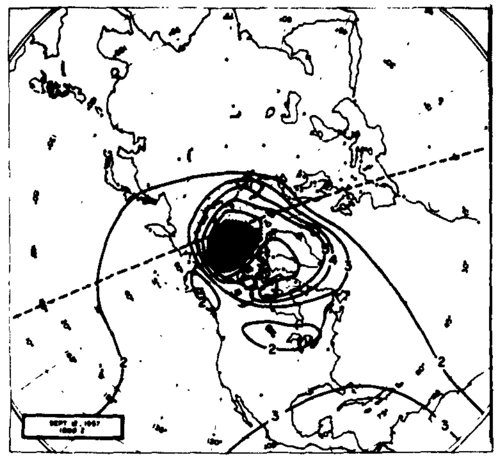


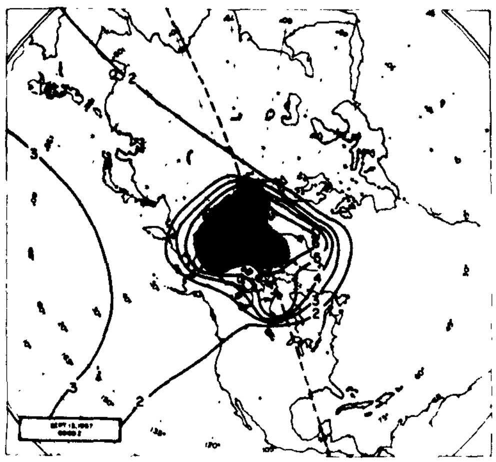


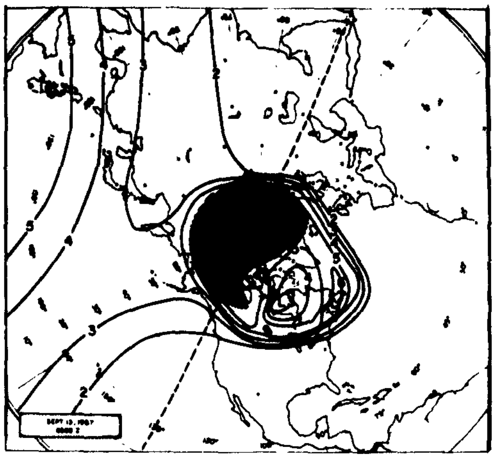


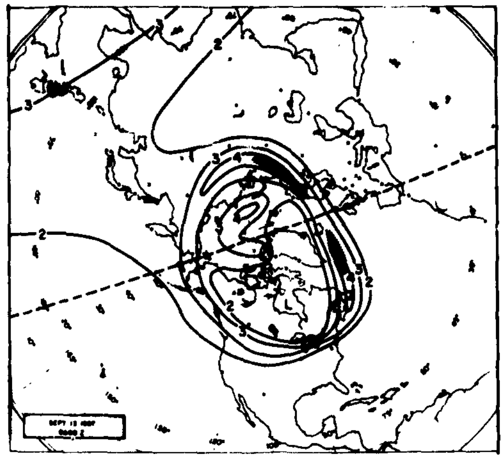
SYNOPTIC fmin CHARTS FOR 12-13 SEPTEMBER 1957











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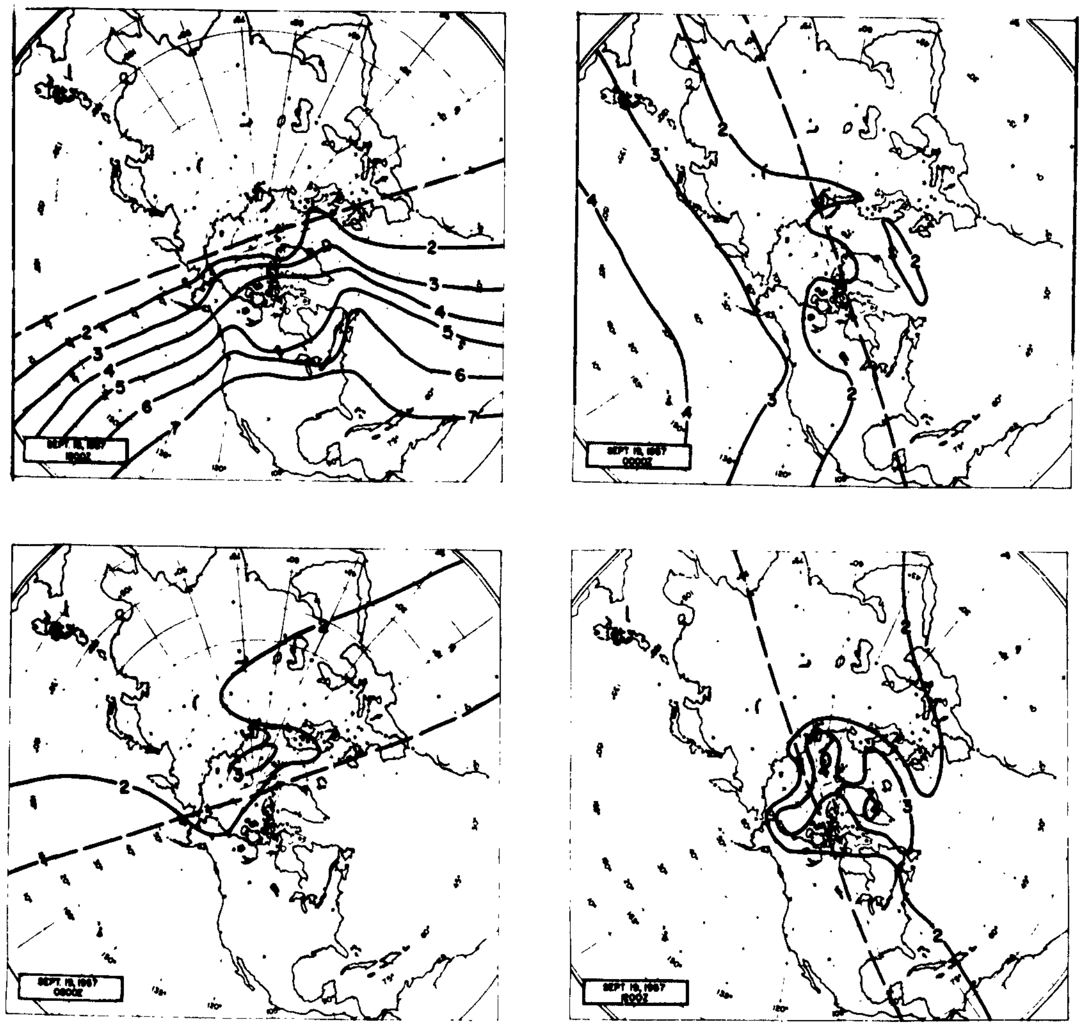

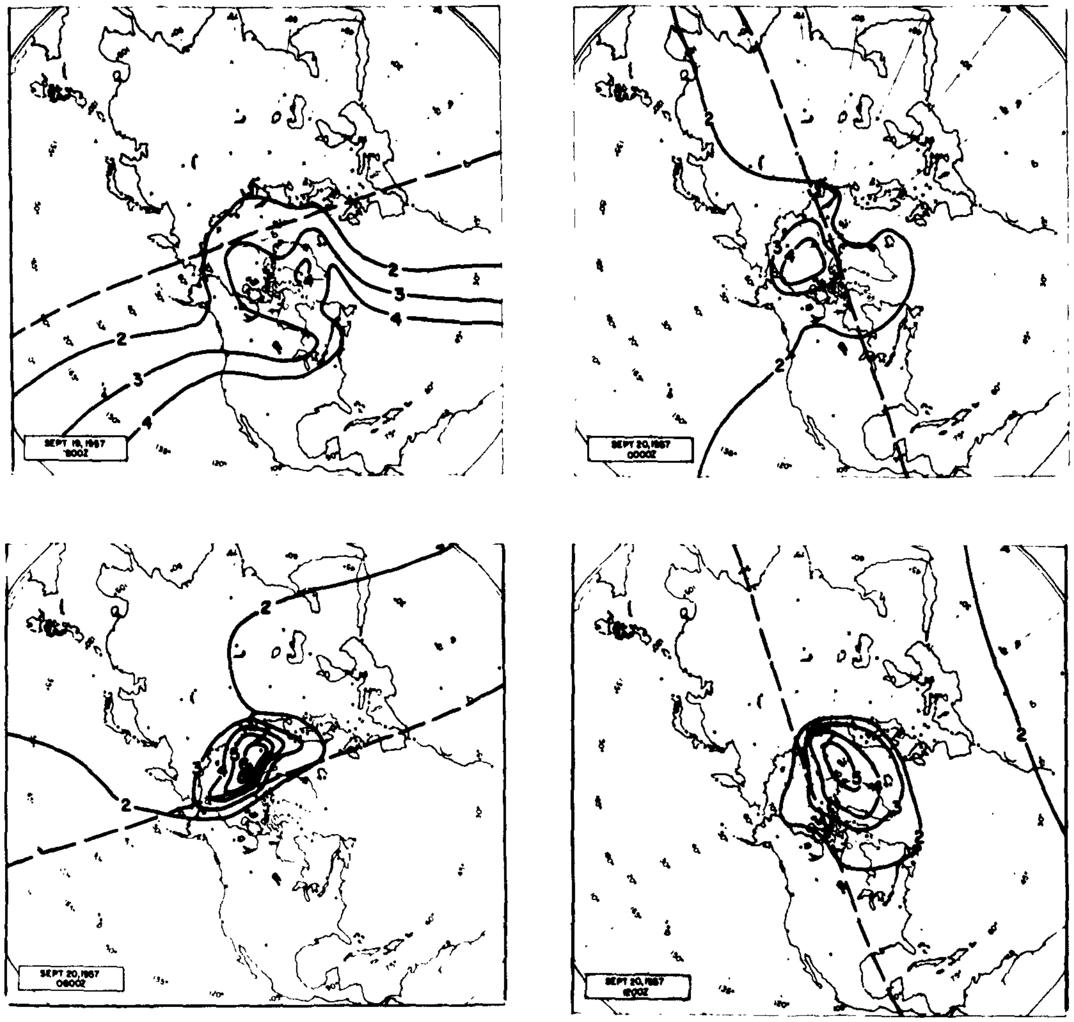
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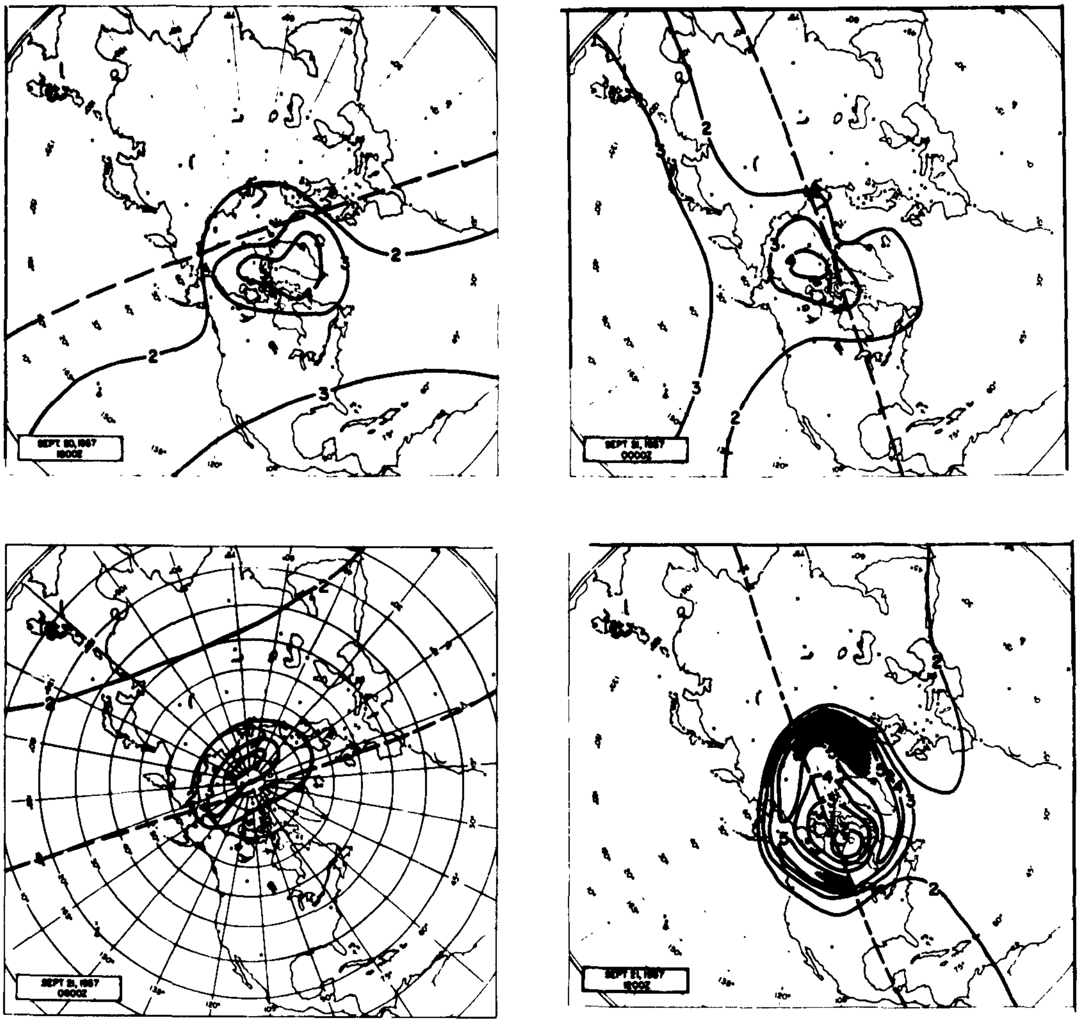
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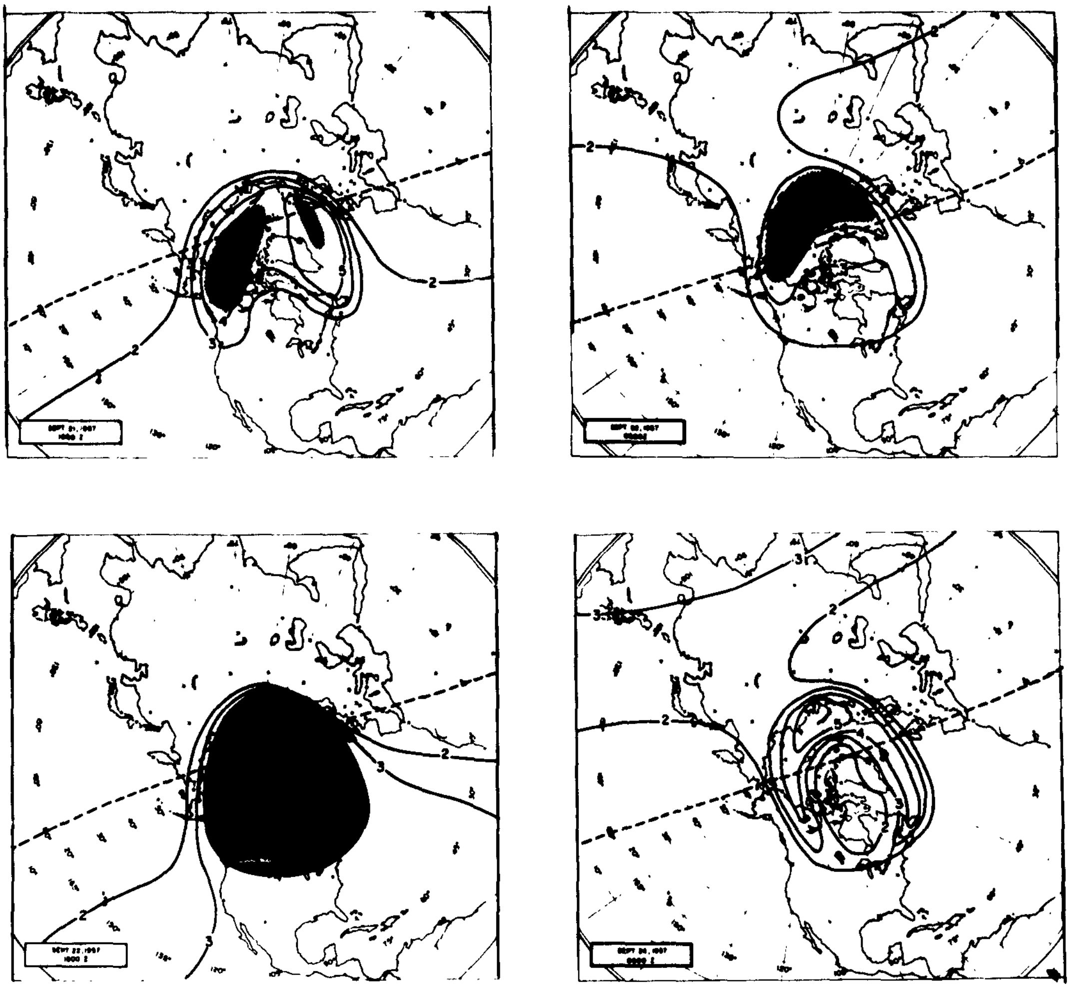

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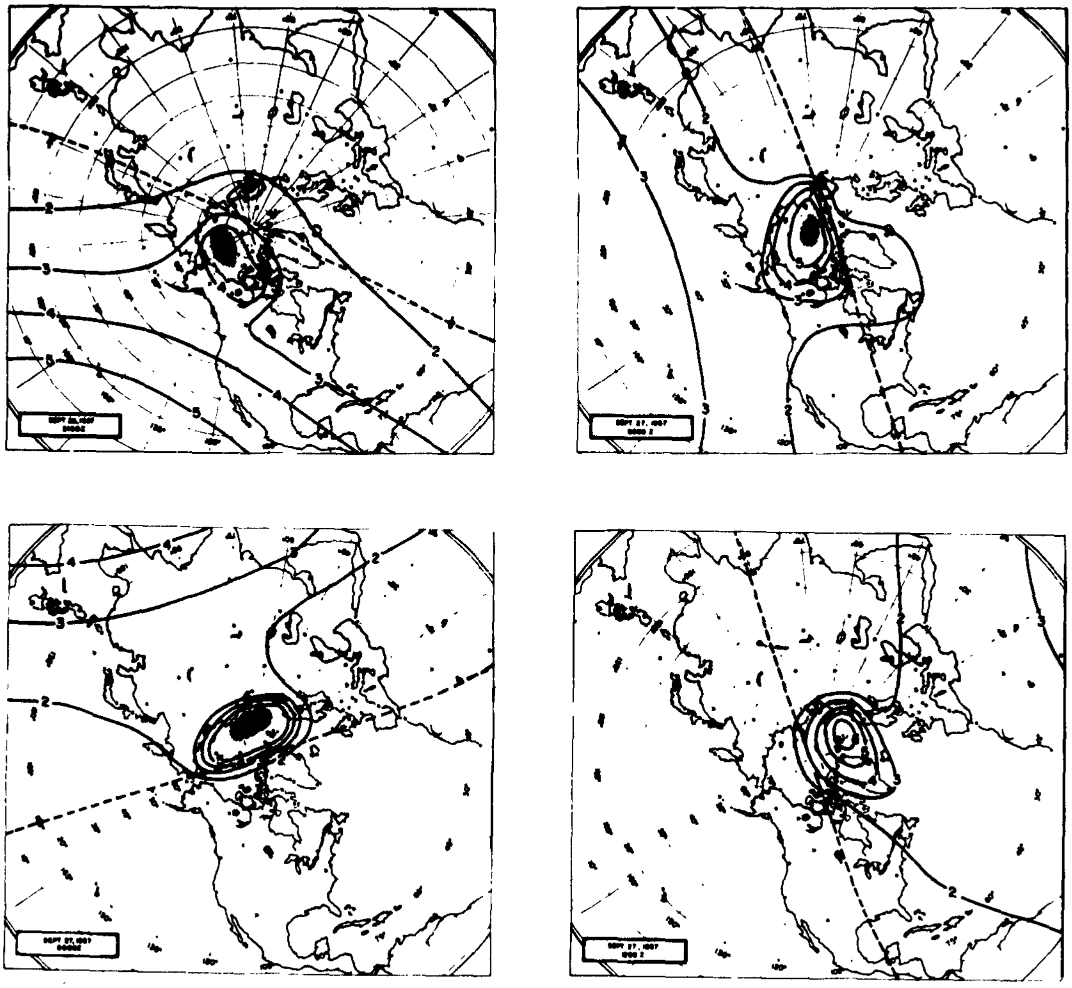
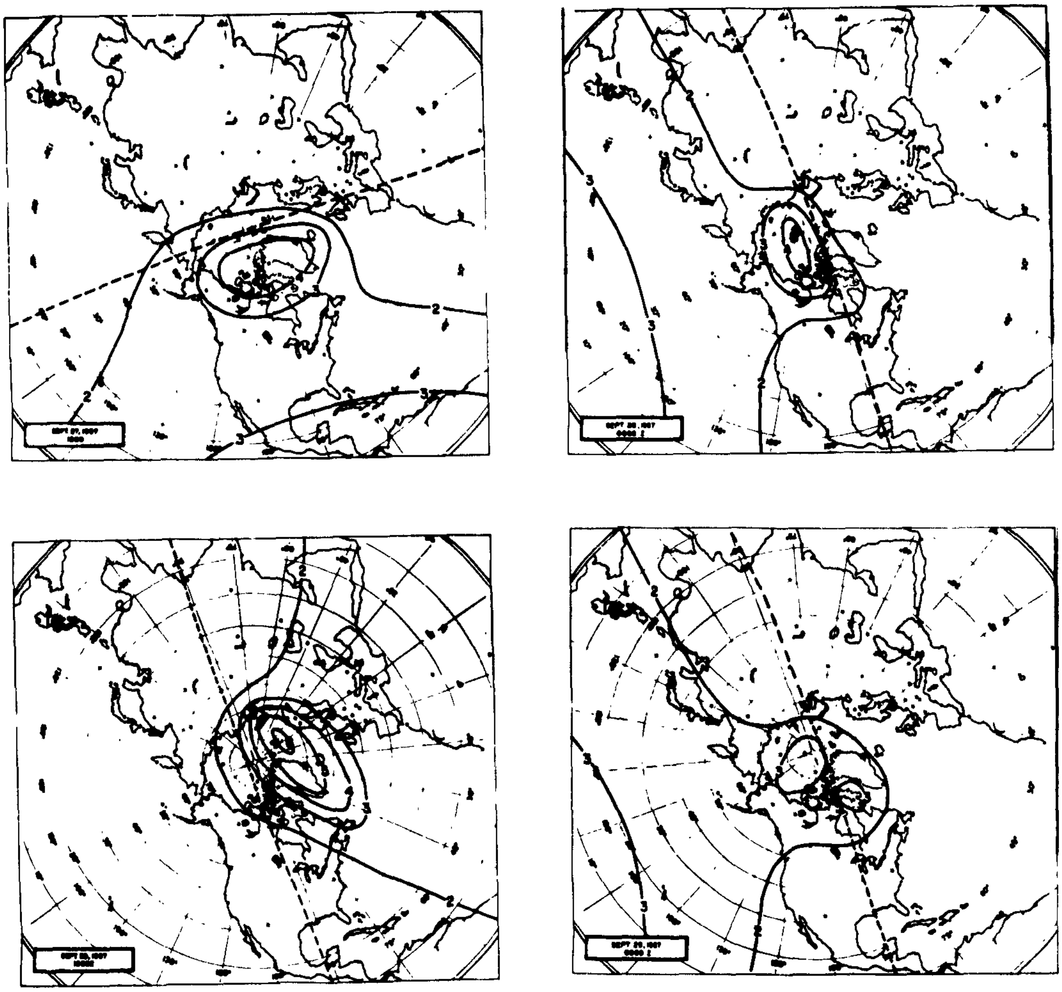
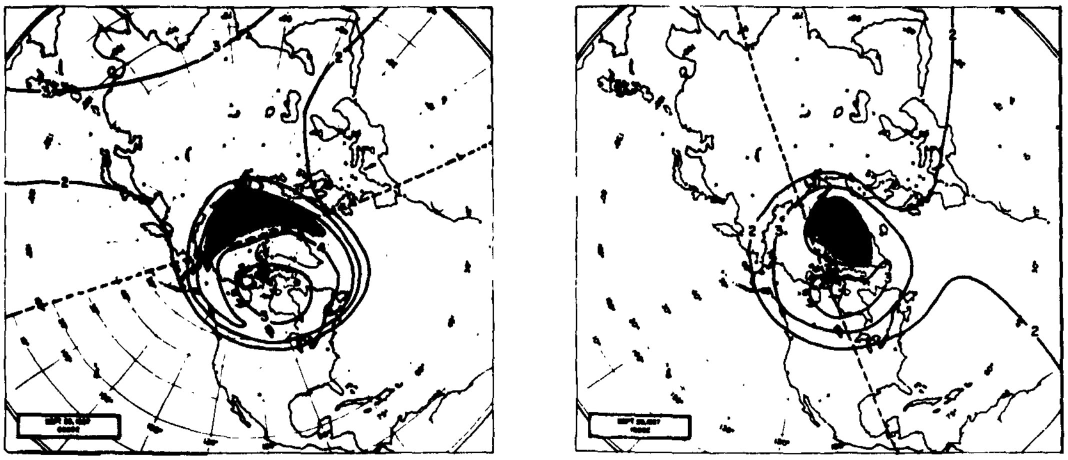
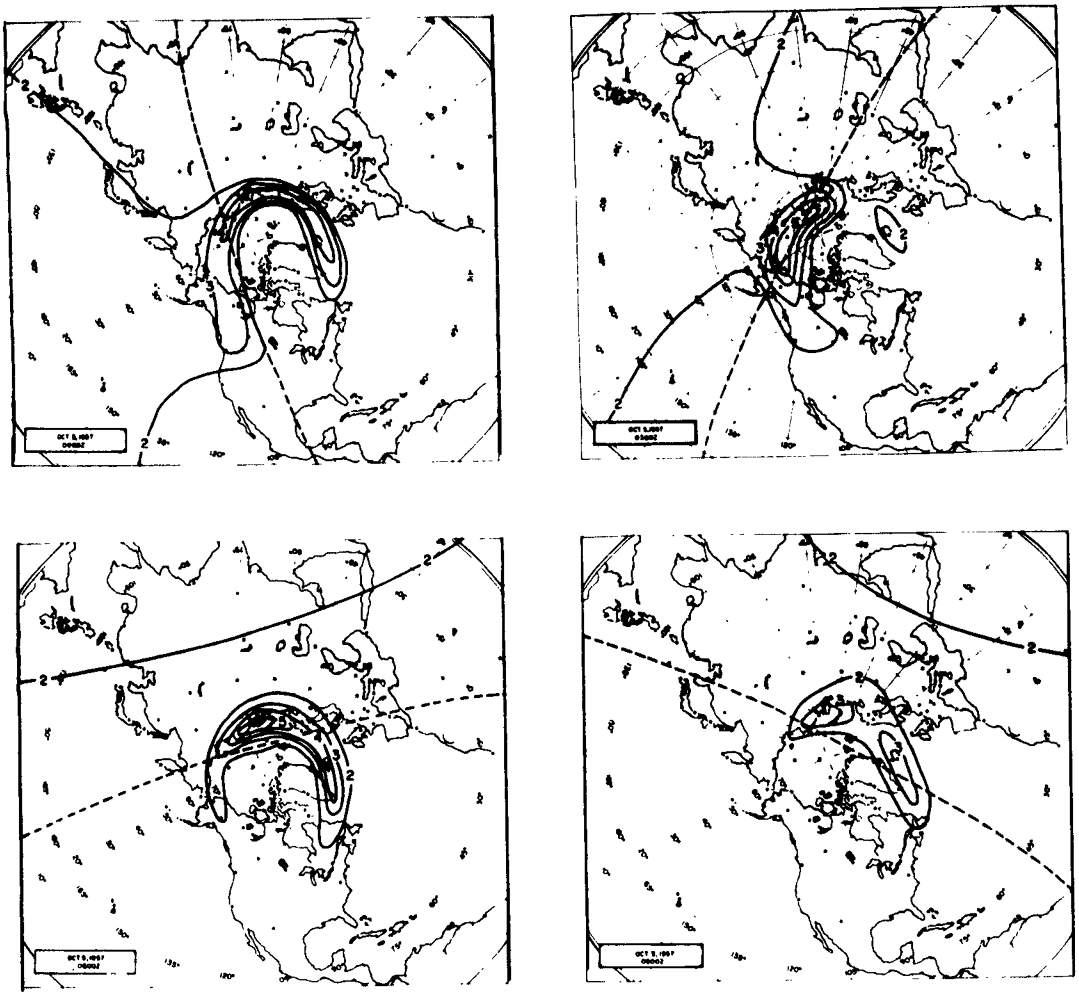






SYNOPTIC fmin CHARTS FOR 5 OCTOBER 1957



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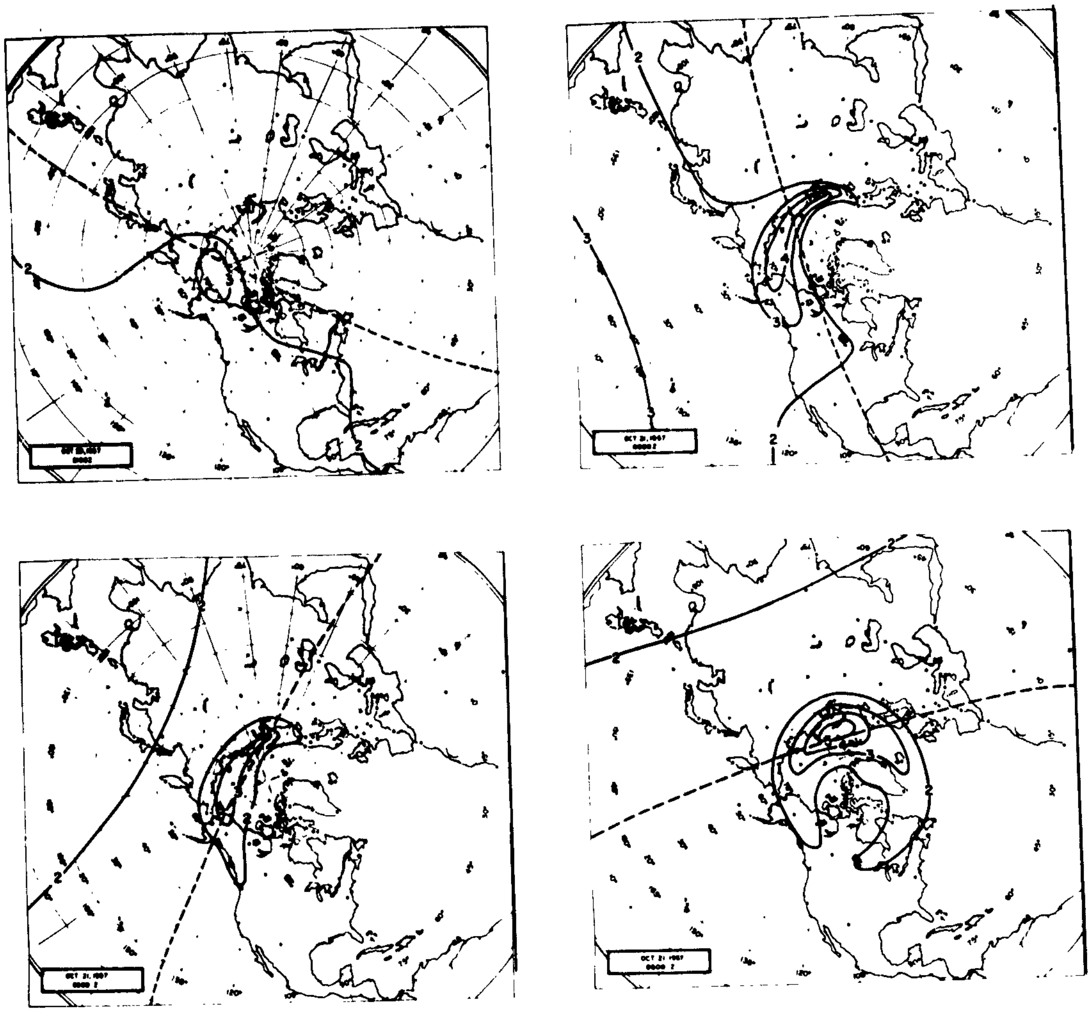

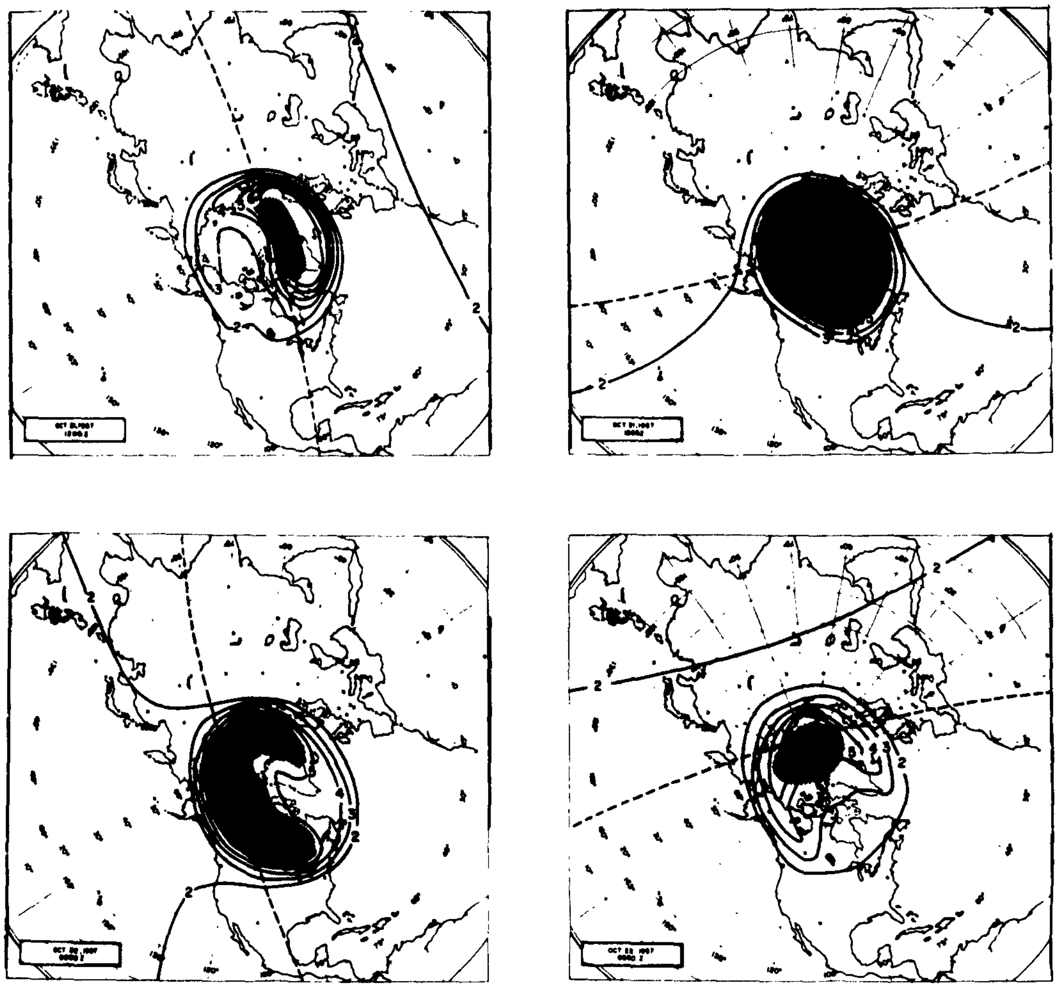

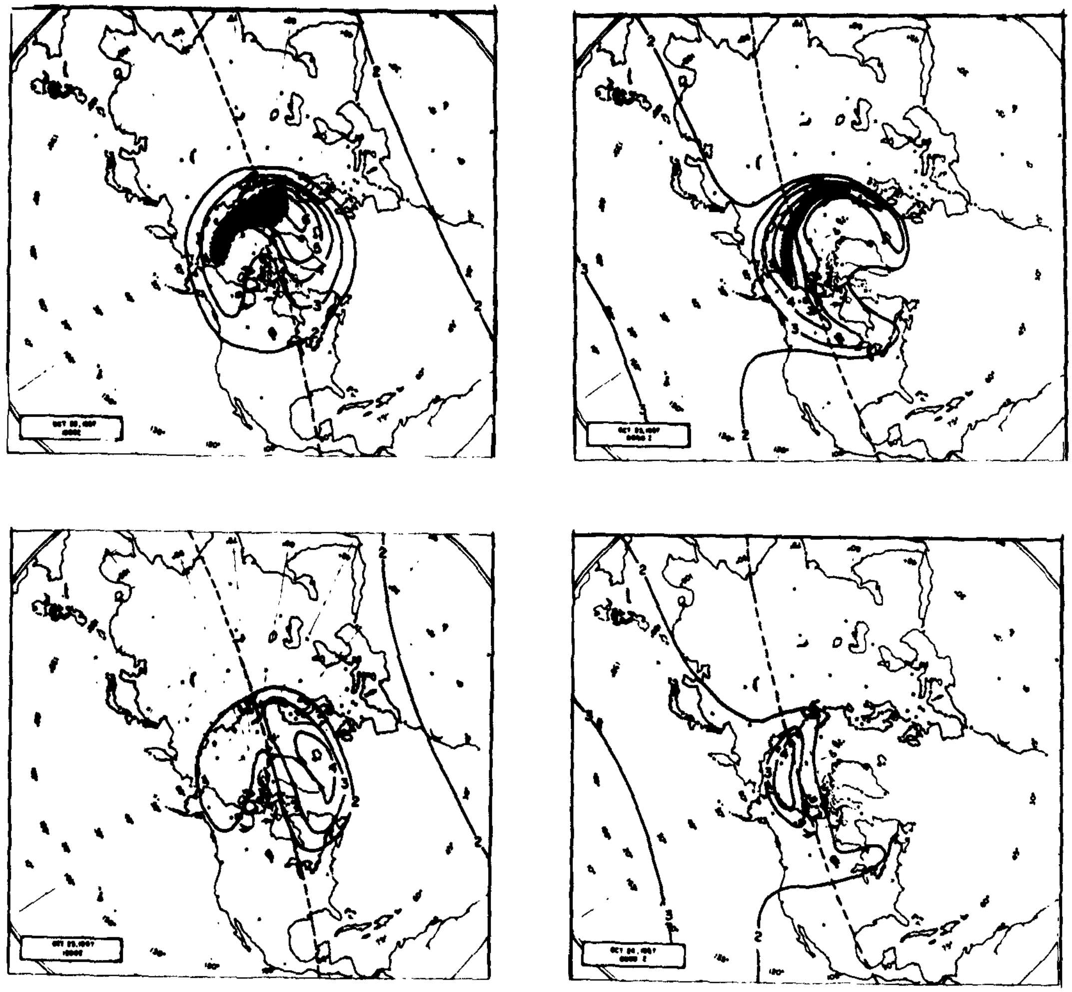

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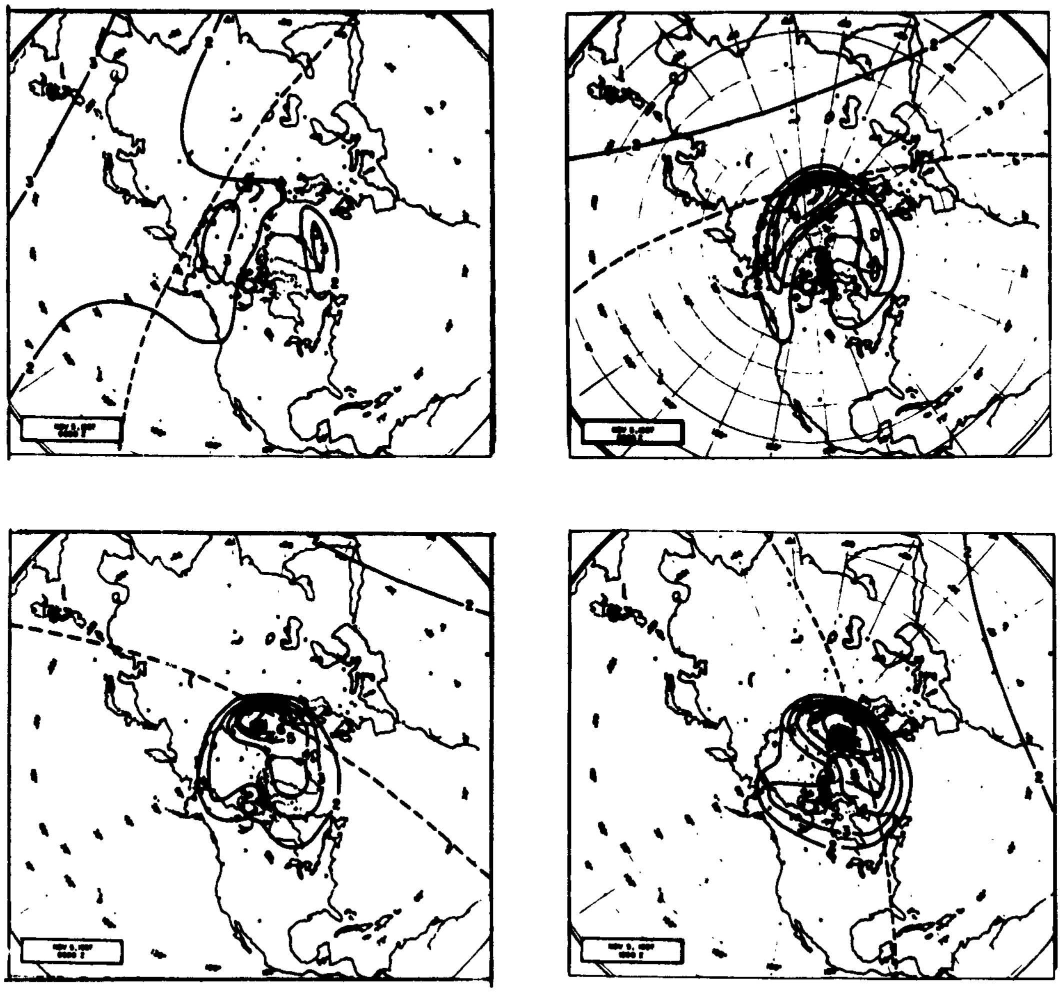

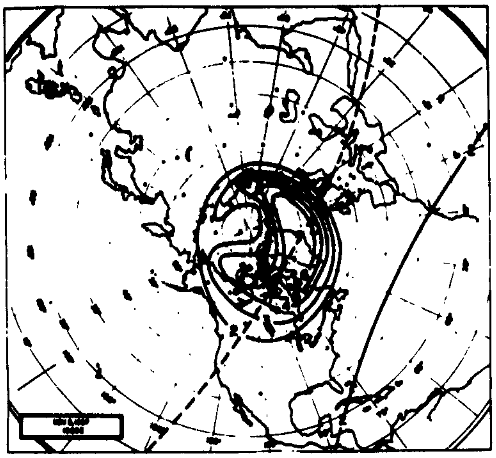

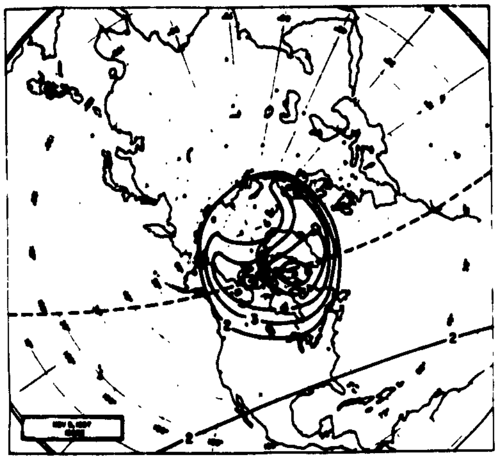

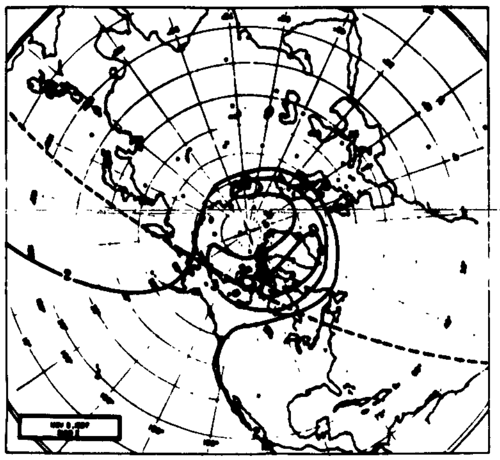

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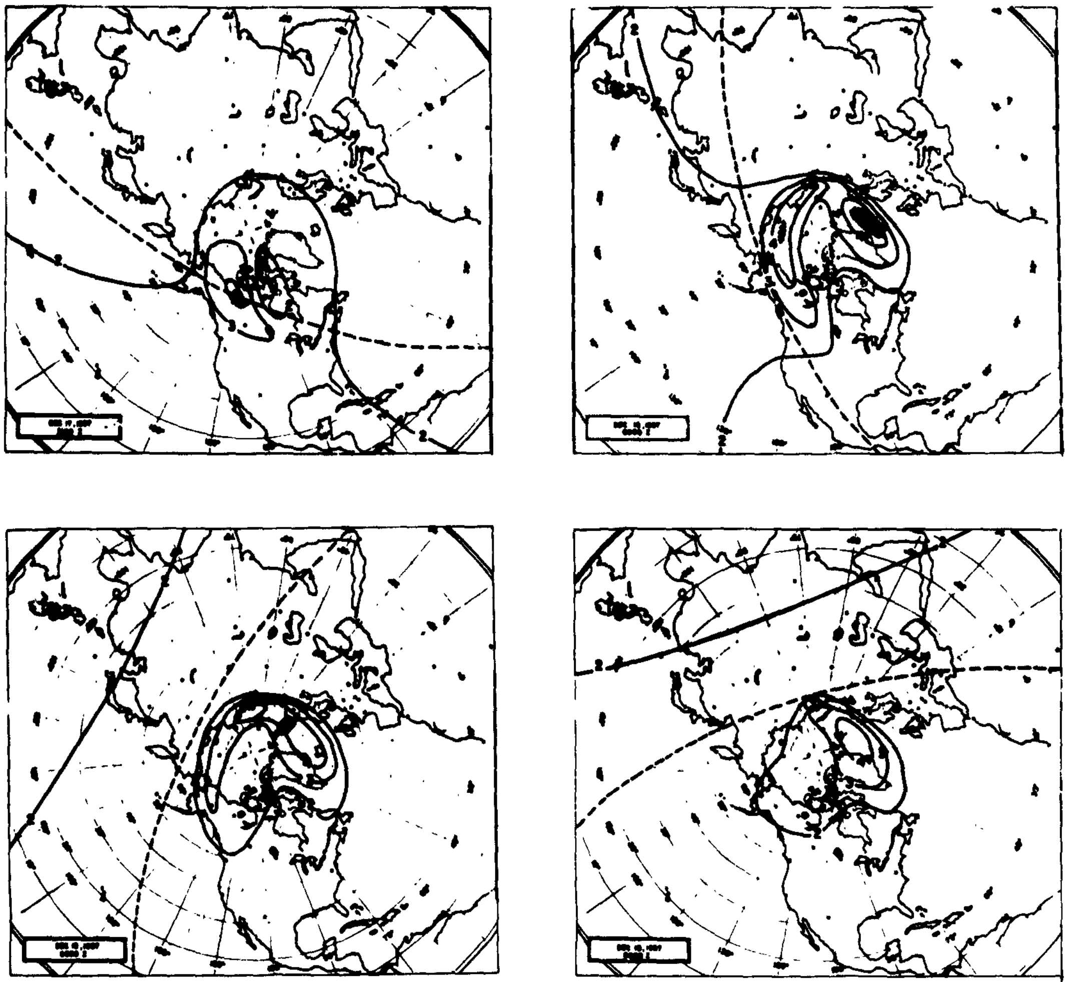

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